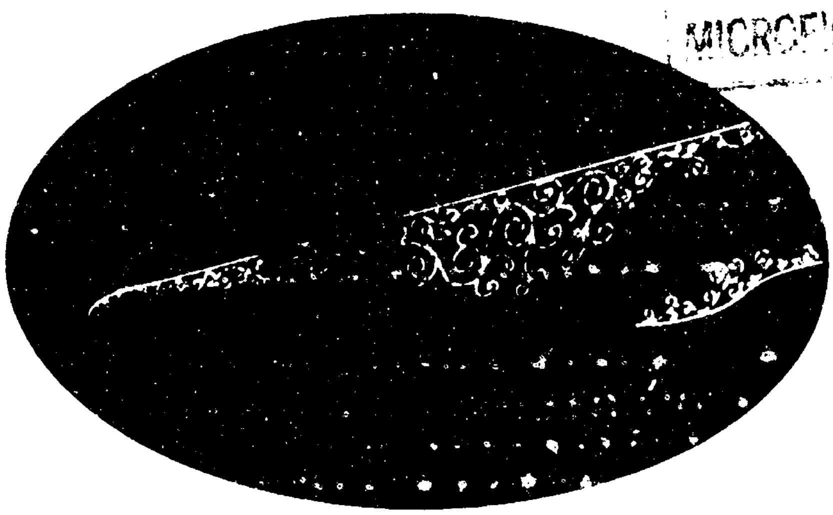
HYDROFOIL MATERIALS RESEARCH PROGRAM
FINAL REPORT

1 JULY 1965



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TASK 1705

Engineering Report 2-53100/5R-2179
21 March 1961 to 1 July 1965

LTV VOUGHT AERONAUTICS DIVISION
LTV AEROSPACE CORPORATION

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ENCLOSURE (/) TO
LTV LETTER NO.
2-53100/5L-1527

FOREWORD

The Hydrofoil Materials Research Program was initiated in March, 1961 by the Navy Department Bureau of Ships under contract NObs 84593. A Phase I report was published in June, 1961 presenting the results of an extensive literature survey of available data on 60 potentially suitable hydrofoil materials and describing plans for the screening test program used in Phase II for selection of the two most suitable materials. The Phase II work was completed in May, 1963 and the test data and analyses developed during this period are presented in reports published in May, 1962 and June, 1963. This is the final report covering in detail the Phase III investigations and summarizing all of the previously reported efforts.

The project has been administered by the Hull and Scientific Branch of BuShips under the direction of Mr. Ivo Fioriti. Acknowledgement is made of the technical contributions and suggestions offered during the final phase of this work by:

Mr. John Vasta, BuShips
Mr. Don Stevens, BuShips
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Mr. Bob Wolfe, NASL

and many specialists within the LTV Aerospace Corporation. Helpful comments and data have also been contributed by personnel of the following companies:

Titanium Metals Corporation
Harvey Aluminum Company
Alloy Castings Institute
Armco Steel Corporation
Republic Steel Corporation

Materials for fabrication of the test specimens were obtained from The United States Steel Corporation, Reactive Metals Incorporated, Lebanon Foundry, the Linde Division of the Union Carbide Corporation, and Mosites Rubber Company, Inc. Personnel of these companies have contributed significantly to this program by comments and suggestions on heat treatment, welding and other processing procedures to obtain optimum physical and mechanical properties of the materials.

ABSTRACT

Sixty materials were studied to determine their suitability for use in construction of high performance hydrofoils and struts. Of these, seventeen materials were given screening tests for susceptibility to sea water corrosion and impingement erosion, and for comparisons of mechanical and fabrication properties. From this work HY-130 low alloy steel and Ti 7Al-2Cb-1Ta titanium were selected for development of design and fabrication data. The HY 130 suitably protected from the sea water environment with a neoprene coating is available for use. The titanium alloy shows many advantages but must have alloy changes to preclude stress corrosion cracking before economic benefits can be realized.

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SUMMARY

Phases I and II of this program reviewed the literature to determine promising material and provided a screening test program using the resistance of the materials to a 90 knot hydrofoil marine environment, strength to weight ratios, impact toughness, material availability, and manufacturing ease as the primary criteria for materials selection. As a result of this survey and the screening tests, the stainless steels and common aircraft steels were found to be lacking in one or more factors when used in the as-welded condition. An epoxy resin-glass laminate looked promising except under long term sustained stress, but its use would require a development effort beyond the scope of this program. No casting alloys which met all the requirements for a 90 knot continuously submerged hydrofoil were tested; however, later tests on 17-4PH given a H-1100 age looked very promising for use in short lived experimental foils. Coatings to protect low alloy steels in the 130 to 150 KSI yield range show promise. An eighty mil cured-in-place neoprene resisted both 90 knot impingement and the cavitation environment, but a need is indicated for additional studies of the primer and surface preparations to prevent undercutting corrosion occurring at exposed edges. The titanium alloy Ti 6Al-4V appears very promising except for failure to meet the high toughness requirements and excessive metal loss at high cavitation intensities. Ti 7Al-2Cb-1Ta, which was selected for final evaluations and design data development is also a promising titanium alloy with excellent properties except for susceptibility to high intensity cavitation and a recently discovered susceptibility to stress corrosion cracking which will necessitate alloy changes. Mil-S-16216 low alloy steel heat treated to the 130-150 KSI yield range and provided with a protective coating appears to satisfy all the requirements for an intermediate strength-weight ratio material for the ninety knot foil. Further development of the necessary coating for use with this steel is required.

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TABLE OF CONTENTS

1.0 INTRODUCTION

The Hydrofoil Materials Research Program was initiated by the Bureau of Ships in order to compare the basic physical and mechanical properties of the structural materials that can feasibly be considered for hydrofoil construction, to select several of the most suitable and economical materials, and, subsequently, to develop the design and fabrication data necessary for efficient construction of high speed hydrofoil structures.

Phase I of this program accomplished the preliminary accumulation of available published and unpublished pertinent data for approximately sixty candidate materials. These data were correlated and analyzed to compare the suitabilities of the materials and to select a limited number of materials to be subjected to a comprehensive screening test program in Phase II. The results of the Phase I effort have been published in reference 1.

The primary objective of the Phase II effort was to select two structural materials which appeared most suitable for hydrofoil construction from the corrosion and erosion resistance standpoint and in terms of the structural efficiency and production cost.

The Phase II effort consisted of the screening tests described in reference 1 to determine corrosion and erosion resistance and mechanical and fabrication properties of 17 materials and coating and cladding combinations which were selected as a result of the Phase I effort. In addition, studies were made of typical hydrofoil designs to provide a basis for fabricability evaluations using the fabrication experience gained in the manufacture of the test specimens and in continued monitoring of available data sources. The objective of this work was to select the two most suitable materials for hydrofoil construction. The results obtained during the Phase II effort have been published in references 2 and 3 and the conclusions are summarized in Section 2.0.

Phase II also included the preparation of the test and analysis program for the Phase III work as outlined in references 2 and 3 and subsequently modified as shown in this report. In addition, complete results of static corrosion tests which are more meaningful after this time period are published herein. Also, some Phase I and Phase II data are published herein to give a more complete picture for the low alloy steel and titanium alloys.

The Phase III effort has developed design and fabrication data for efficient construction of high speed hydrofoil structures using Ti 7Al-2Cb-1Ta and coated HY 130. The data presented include direct design information; i.e., longitudinal and transverse tensile and yield strengths and elongations for welded and unwelded material, corrosion-fatigue S-N curves for welded, unidirectional tension stresses and calculated allowable compression and shear buckling stresses. Other data include Charpy V notch and drop weight tear test toughness values, sea water static corrosion and impingement erosion-corrosion characteristics and cavitation-erosion-corrosion susceptibilities. Impingement erosion-corrosion testing was conducted in both the water wheel facility at LTV and the jet erosion facility at the International Nickel Company using natural sea water. Cavitation testing was done in the water wheel facility and in the rotating disc facility at the Naval Applied Science Laboratory.

Fabricability is presented in the form of fabrication indices for welding, machining, forming and processing. The fabricability data place major emphasis on the problems associated with actual construction of hydrofoils. In addition to the tests run specifically to develop fabrication indices, additional design data were obtained from fabrication of the test specimens.

2.0 DISCUSSION OF LITERATURE SURVEY AND PHASE I AND PHASE II DATA

2.1 PHASE I

Phase I of this program accomplished the preliminary accumulation of available published and unpublished data for approximately sixty candidate materials. These data were correlated and analyzed to compare the suitabilities of the materials and to select a limited number of materials to be subjected to a comprehensive screening test program in Phase II. The results of the Phase I effort have been published in the Phase I report, reference 1.

2.2 PHASE II

The Phase II effort consisted of the screening tests described in references 2 and 3 to determine corrosion and erosion resistance and mechanical and fabrication properties of seventeen materials and coating and cladding combinations which were selected as a result of the Phase I effort. In addition, studies were made of typical hydrofoil designs to provide a basis for fabricability evaluations using the fabrication experience gained in manufacture of the test specimens and in continued monitoring of available data sources. The objective of this work was to select the two most suitable materials for hydrofoil construction. The conclusions drawn after the Phase II effort are summarized below.

2.2.1 INCONEL 718

This high nickel alloy was heat treated to 170 ksi tensile yield strength with 20 percent elongation in two inches It is excellent in resistance to cavitation, erosion and general corrosion metal losses, but is subject to slight crevice corrosion. It exhibits good corrosion fatigue properties, has a ductile failure at zero degrees fahrenheit, and is not subject to stress corrosion cracking. Restrained plate can be welded with Rene' 41 filler wire and aging accomplished after welding without serious warpage problems. This was considered a promising material for hydrofoils but was dropped from the program because of high costs for materials and manufacturing methods in comparison with materials in the same performance class.

2.2.2 K MONEL

This nickel alloy, heat treated to a 95,000 tensile yield strength and an elongation of 17 percent in two inches, is marginal in strength properties. Corrosion fatigue values are satisfactory, and it is not subject to stress corrosion cracking in a marine environment when stressed to 90 percent of yield. K Monel is, however, subject to moderate crevice corrosion, exhibits relatively high erosion and cavitation metal loss rates, and presents a fabrication problem due to its required 1400°F stress relief after welding. Due to these latter characteristics, K Monel was not recommended for further effort in this program.

2.2.3 17-4PH(H1025)

17-4PH stainless steel in the H1025 condition resulted in a tensile yield value of 167,000 psi and an elongation of 14 percent in two inches. The metal loss rates from corrosion, cavitation and erosion in the conditions tested were generally greater than for the other unprotected materials in Phase II. Pitting and crevice corrosion progressed at an unsatisfactorily high rate in the static corrosion tests, and unprotected material is considered marginal for use even in retractable foils where crevices would be intermittently wet and dry during long intervals of time. Phase I literature survey indicated, reference 6, that fatigue values in a sea water environment are decreased to a relatively low value when compared to the titanium alloys and Inconel 718. These test results indicate that without a protective coating 17-4PH is unsatisfactory for continuously submerged or retractable hydrofoil use; however, reference 8 indicates that this corrosion can be eliminated by proper control of the columbium - carbon ratio.

The work of LaQue and Ellis, reference 7, points out that the severity of attack in a crevice of a corrosion resistant steel is related to the area of adjacent unprotected surface. This area effect in crevice corrosion indicates that a firmly adherent coating system with few pores would substantially decrease crevice corrosion in this alloy even after coating damage. Aging at 1025°F is preferable to 1075°F according to Armco impact test data, reference 9. Izod impact testing of welded specimens with a 1000°F age resulted in ductile failures without the necessity for an intermediate solution anneal. This material with an 1100°F age and no solution anneal after welding gave markedly lower impact values.

Because of the superior fabrication properties and because of the higher strength obtained without susceptibility to stress corrosion, 17-4PH(H1025) would have been considered for Phase III work with a neoprene coating; however, the requirement for an aging treatment after welding to obtain necessary toughness was considered uneconomical for large, built up foil structures.

2.2.4 TITANIUM 6Al-4V

This alpha beta alloy heat treated to 141,000 tensile yield and 11 percent elongation in two inches has given an excellent performance in the screening tests of Phase II. Its excellent corrosion properties result in essentially no reduction in fatigue values in sea water, no stress corrosion cracking, essentially no effect in static corrosion, and no accelerating effect in the cavitation and sea water erosion tests. Some fabrication problems complicate the picture for a heat treated material which may make the desirability of heat treatment questionable. The material shows ductile fractures in impact testing in temperatures as low as -40°F; however, Charpy V notch energy values were marginal. Due to the ready availability of this alloy in contrast to numerous other titanium alloys, it was considered a prime candidate hydrofoil material.

Recent rotating disc cavitation tests on the Ti 6Al-4V and Ti 8Al-2Cb-1Ta titanium alloys at the Material Laboratory, New York Naval Shipyards, have shown a relatively large material loss under cavitation conditions which are believed to be extremely severe. These tests indicate that cavitation resistance is excellent at 100 and 125 fps, but that a much lower resistance was noted at 150 fps. This material was considered for Phase III evaluation until Ti 7Al-2Cb-1Ta alloy became available.

2.2.5 TITANIUM 8Al-2Cb-1Ta

The Ti 8Al-2Cb-1Ta alloy, except for a lower tensile strength than the heat treated Ti 6Al-4V, was believed to combine all the advantages of the Ti 6Al-4V with a lower nil ductility transition temperature and greater toughness at 32°F. Weld cracking of restrained welds caused this material to be changed to the Ti 7Al-2Cb-1Ta evaluated in Phase III.

2.2.6 BERYLLIUM COPPER

Beryllium Copper (Berylco-25) showed satisfactory corrosion resistance and did not support fouling growth. Weight loss in cavitation was satisfactory, but erosion losses were high. Brittle failures occurred at 0°F in Charpy V notch impact tests and corrosion-fatigue properties were low. Because of the latter characteristics, beryllium copper did not receive further effort in Phase III.

2.2.7 METAL CLAD PLATE

A corrosion and fatigue resistant cladding over a high strength base metal appeared to be an attractive material combination in the Phase I evaluation. In this program Hastelloy C and commercially pure titanium (A-70) were chosen as cladding materials for their corrosion and fatigue properties. AISI-4330M and HY 100 were chosen as materials with the necessary strength and toughness for base metals. The four materials were processed to simulate the respective cladding-rolling operations and the subsequent hardening and tempering necessary for base metal strength development. Since actual clad material combinations were not available to this program, each material was processed separately.

2.2.7.1 Titanium Cladding (A-70)

The commercially pure titanium was found to be severely embrittled due to gettering action during the simulated cladding process. Lukens Steel reported that this material would be a very difficult one to use as a cladding for this reason, and it was therefore dropped from the program.

2.2.7.2 Hastelloy C Cladding

The Hastelloy C performed well in 90 knot erosion cavitation tests when processed for cladding on both HY 100 and AISI 4330M. The static corrosion and corrosion fatigue results were excellent. Charpy V notch impact tests at 0°F resulted in brittle failure which is a detrimental factor because of the possibility of a crack at the surface setting up a stress concentration in the base metal as well as causing a galvanic corrosive action at the break between the cladding and the base metal. For this reason, this material was not recommended for Phase III testing.

2.2.8 ELASTOMERIC COATINGS ON LOW ALLOY STEEL

Elastomeric Coatings on low alloy steel appeared to be a method to combine the strength and durability of a base material with the protection a coating may offer from erosion, cavitation and corrosion. Following are some of the advantages of an elastomeric coating system as compared to a metal cladding:

- The mechanical or physical properties of the base material are not affected by the coating application.

- A break in the coating does not set up a galvanic couple or a stress concentration.

- The coating can be applied as a calendered sheet during fabrication and can be repaired readily in service.

2.2.8.1 AISI 4330M

AISI 4330M heat treated to the 160 KSI yield strength range showed satisfactory elongation and Charpy V notch toughness at 0°F. It showed high corrosion, erosion and cavitation losses and a low corrosion fatigue life. However, test data obtained during Phase II indicated that elastomeric coating may correct these deficiencies. It is hardenable through a one-inch plate thickness and does not require extensive preheats and post heats to prevent weld cracking. Heat treatment after welding to develop strength of this material may present serious distortion problems during fabricability. Toughness in the as-welded condition is not as high as HY 100 heat treated to 130-150 KSI yield range so that this material was not tested in Phase III.

2.2.8.2 HY 100

HY 100, although it has a marginal strength-to-weight ratio, has excellent elongation and toughness. Uncoated HY 100, like AISI 4330M, has a low resistance to cavitation, erosion, and corrosion, and has a low fatigue life.

Because of low material costs and the possibility of improving all the deficient properties with a reliable coating, HY 100 heat-treated to the 130-150 KSI yield strength range was recommended for retention as base material in Phase III studies.

2.2.9 EPOXY RESIN-GLASS LAMINATES

Epoxy resin-glass laminates were included as a base material in the Phase II materials studies because of their inherent resistance to the corrosive effects of sea water and the excellent strength to weight ratio (530 psi per pound per cubic foot for isotropic Scotchply Type 1009 at 70°F).

In considering the various resin-glass laminates, a neoprene coated epoxy system was chosen because of excellent strength characteristics and rain erosion resistance that has been demonstrated in aircraft service. Scotchply 1000 preimpregnated (Minnesota Mining and Manufacturing) was chosen because of its suitability for use with the mercury bag molding process of Hudson Engineering Company. This process, in its present state of development, is limited to a 225°F curing temperature. Thus, Scotchply 1000 with its background of usage in thick springs for vehicles, curing temperatures in the 225°F range, and with the capability for use in section thicknesses up to the six inch appeared to be well suited to hydrofoils usage.

An acceptable Charpy V notch fracture energy was shown, and only a slight roughening resulted from the jet erosion test in the uncoated state. In the unidirectional fatigue test a substantial loss in modulus of elasticity was experienced. The resulting excessive bending deflection exceeded the deflection limits of the test equipment and precluded completion of the test. Subsequent investigation revealed that the 225°F curing temperature, as presently limited by the Hudson Engineering Process, does not produce a fully-cured resin matrix. An additional 16 hour, 300°F cure increased the Barcol hardness at 160°F from 59 to 66 and resulted in significantly improved fatigue properties.

A neoprene-coated specimen, loaded to 60,000 psi bending stress, failed after 23 days in sea water. Figure 3-18 of reference 10 shows reasonable correlation with these data.

Because of the developmental nature of this material and fabrication process and because of initial test failures obtained, epoxy resin glass laminate was dropped from the Phase III program; however, further investigation of the material is indicated.

2.2.10 CASTINGS

AM-355 and CD 4 MCU casting materials were considered for nacelle structure and other irregular shapes on the hydrofoil. The jet erosion and cavitation resistance of CD 4 MCU was excellent, although some crevice corrosion did occur. As welded AM 355 stress corrosion specimens failed within 65 days, and the Charpy V notch impact failures of both materials were brittle at 0°F which eliminated the materials for further consideration.

3.0 REVIEW OF MATERIAL SELECTION

The basic objective of the Hydrofoil Materials Research Program was to select the most suitable materials for the fabrication of hydrofoil structural components. The original list of sixty materials for the program was compiled from available information indicating desirable properties in one or more characteristics being considered. A subsequent literature survey, an extensive screening test program, continual monitoring of government and private sources of information, and comparative cost analyses provided the data for the final selection of Ti 7Al-2Cb-1Ta and coated HY 130 as the two most suitable materials for hydrofoil structures.

Most of the materials that were rejected in the screening tests were considered unacceptable from a safety standpoint such as impact brittleness and stress corrosion cracking which could cause catastrophic failure of critical foil structure. Toward the end of the Phase II work, it became evident that a number of materials would meet the physical requirements of hydrofoil use and that final selection of two materials would require a cost comparison. It was also considered logical that one selected material should be inherently resistant to the sea water environment and that one should require a protective coating. The final comparison of several materials in each category was based on estimated costs of materials, tooling, and fabrication that would be required for a typical foil structure. This comparison is reported in reference 3.

At the time this comparison was made, the development of Ti 7Al-2Cb-1Ta alloy was not completed and Ti 6Al-4V was recommended as one selected material. The substitution of Ti 7Al-2Cb-1Ta for Ti 6Al-4V was made early in Phase III upon its availability.

3.1 MECHANICAL PROPERTIES AND STRENGTH-WEIGHT RATIOS

There are many materials - alloys of steel, titanium, nickel and copper - which can provide greatly improved tensile and compressive properties over materials presently used in shipbuilding, and even in present prototype hydrofoil structures. If these were the only requirements, extensive weight savings could be realized in their use. In all cases other influences, mainly environmental, either prohibited the use of these materials or required compromises to such an extent that the advantages were nullified. Stainless steels, such as 17-4PH could provide considerable weight advantages over HY 130 except that in order to get adequate toughness in welded structures, a 1500°F post weld treatment is necessary. This makes 17-4 tooling significantly more expensive than that required for HY 130 steel. Inconel 718, which shows excellent resistance to corrosion, showed a fabrication cost comparable to that of titanium with a significant weight disadvantage. Ti 6Al-4V showed a weight and, therefore, a cost advantage over Ti 7Al-2Cb-1Ta; however, the toughness of this material is below the minimum requirements established by the Navy for hydrofoil structures.

3.2 TOUGHNESS CRITERIA FOR FINAL MATERIAL SELECTION

Toughness requirements for hydrofoil materials have been patterned largely after those for submarines. In reference 25, Sorkin and Willner showed that a Charpy V-notch energy of less than 21 foot pounds at 0°F would result in brittle fractures in high strength titanium plate (110 KSI minimum yield strength). Later investigations, references 11, 13, and 14 at NRL have correlated brittle fractures in service with test data for several types of tests, namely, explosion bulge, explosion tear, drop weight tear and Charpy V-notch. Analyses of these data indicate that drop weight tear test energy values of 3,000 and 2,000 foot pounds for steel and titanium respectively are required to provide adequate toughness for deep submersible vehicles. Although the toughness requirements for hydrofoil structures to resist the impact of floating obstructions is different and possibly less severe than the underwater explosions that submarines are exposed to, these criteria have been used in determining the final material selection for this program.

Many of the candidate hydrofoil materials were eliminated from the program because of deficient toughness. In most materials the impact toughness is an inverse function of the yield and tensile strengths and, consequently, where strength levels can be controlled by heat treatment, there is a corresponding toughness control. The strength-toughness relationship differs substantially for different materials and even for different alloy compositions of similar materials. Ti 7Al-2Cb-1Ta and Ti 8Al-2Cb-1Ta are the only titanium alloys investigated in the hydrofoil materials program which met the minimum toughness requirement. Ti 6Al-4V (ELI) with a special anneal at the beta transus temperature and Ti 5Al-2.5 Sn showed significant toughness improvement over higher strength titanium alloys but fell short of the conservative requirements set understandably high for new materials in a new design. In all cases, the weld toughness of titanium alloys was at least as high as that of the parent material.

HY 130 was the only steel tested in the program which provided adequate toughness. Here, also, the weld toughness essentially equalled that of the parent material.

3.3 CORROSION, IMPINGEMENT, CAVITATION RESISTANCE

Corrosion resistance was extensively evaluated during the Phase II materials selection effort because it plays such a large role in a number of associated properties. The rate of metal loss in cavitation and high angle sea water impingement was seen to be related to the corrosion resistance. Alloys which had fairly high static corrosion rates became unacceptable from a corrosion standpoint when either ninety knot sea water impingement or cavitation erosion were added as a second factor. HY 130 was the only material which possessed the required values of characteristics other than corrosion resistance and could be fabricated at low cost. Thus, only HY 130 with a yield strength range of 130-150 KSI was considered worth the additional costs of applying and maintaining a coating system to protect it from the combined influence of these three factors.

Stress corrosion cracking was considered to be an unacceptable phenomena. The risk was considered too high to seek a coating protection for an alloy and its associated heat treatment which cracked in a corrosive environment. Thus, strength levels for HY 130 could not have been raised much because of the limiting factors of weld toughness and strength for this alloy in the 150 KSI range. Titanium alloys in Phase II, as had been indicated for other titanium alloys in the literature, were immune to all types of corrosive attack except severe cavitation. Impingement resistance in sea water once again confirmed this advantage by showing negligible loss in thirty days at ninety knots. Losses of metal due to cavitation showed a definite threshold condition somewhere between 125 and 150 feet per second with the cavitation generator of the Naval Applied Science Laboratory rotating disc. In this region, severe losses of metal began. This indicates that designers will definitely have to take cavitation into consideration as higher performance foils are developed. However, this seems to be a minor disadvantage in relation to the other excellent properties.

From the foregoing considerations, HY 100 heat treated to 130 KSI yield strength and Ti 7Al-2Cb-1Ta with a chemistry to develop 100 KSI yield strength were selected for Phase III evaluation.

3.4 RECENTLY DEVELOPED MATERIALS

It should also be mentioned that the 5Ni-Cr-Mo-V steel heat treated in the 130 to 150 KSI range has been under investigation by U. S. Steel and significant data have been published in reference 24. This material has shown excellent toughness properties in welds and heat affected zones as well as the base (wrought) material. Evaluations by U. S. Steel of a number of 80 ton electric furnace heats rolled to two-inch plates and heat treated in the 135 to 145 KSI yield strength range show Charpy V notch toughness from 60 to 90 foot pounds at 0°F. Welding filler metals and welding techniques are being developed in the U. S. Steel program for both MIG and covered electrode. Preliminary data indicate that essentially 100% efficient MIG welding can be attained with only a slight toughness reduction.

This material has shown relatively good stress corrosion resistance in NRL short term tests; however, since data are not available to correlate the short term results to those of the conventional long term bent beam and circle patch weld tests, some checking in this area is recommended. Complete freedom from stress corrosion cracking would merit this alloy serious consideration for use in any future high performance foil structure.

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4.0 DESIGN DATA AND DISCUSSION

The final objective of the Hydrofoil Materials Research Program is to acquire and correlate the available pertinent data on the two final materials. The following sections contain the tables and charts presenting these data in the forms that are considered most useable for the design of hydrofoil structures. The test results developed in this program and, in some cases, supplemented from published sources are included for substantiation of the recommended design information. Where specific design relationships cannot be presented, such as impact toughness, the test values are shown with discussions of recommended approaches to the use of the test data.

4.1 TENSION AND COMPRESSION MECHANICAL PROPERTIES

The objective of this portion of the program was to determine the basic mechanical properties of the candidate materials in both the "as received" condition and fusion welded. Tests were conducted on specimens removed from plates of both 1/4 and 1 inch thicknesses in accordance with the sketch of figure 4.01.

All tests were conducted in a Riehle test machine of 150,000 pound capacity. Autographic load strain traces were obtained with a Baldwin P5-M microformer extensometer and the load indicating mechanism of the test machine. Loading was accomplished at a rate of 0.005 in/in/min to a point beyond yield load and at a head travel rate of 0.20 in/min from that point to failure. Strain tests were controlled through the use of a strain pacer built into the test machine.

The results of all tests conducted during this investigation are presented in tables 4-1 and 4-2. Except as noted, all welded specimens were cut from blanks which were MIG welded as described in section 5.3. For purposes of comparison the following table presents the minimum acceptable values for the materials as processed by the material supplier.

Material	Ftu	Fty	Fcy	%e	R.A.
Ti-7Al-2Cb-1Ta	115,000	100,000	110,000	10	20
HY-130	*	130,000	*	10	*

*No minimum value specified.

Comparison of these values with the results shown in tables 4-1 and 4-2 will show that the average values on control tests of unwelded 1 inch material met or exceeded these requirements, although there were isolated cases of single tests which fell somewhat below these values.

As indicated by the test results presented in table 4-1, weld efficiencies of 100 percent can be attained in a welded titanium structure.

As discussed in section 4.4 of this report, all HY-130 steel was procured in the yield strength range of 140 to 145 ksi in order that toughness might be evaluated for the potentially critical material strength level. The strength level of this "as received" material is shown in table 4-2 for unwelded 1 inch plate material. Initial welding trials as discussed in section 5.3 of this report indicated that weld efficiencies in this high-strength level material would range from 95 to 100% as shown by the supplementary data presented in table 4-2.

In order that weld strength might be established for material which was representative of minimum acceptable properties (F_{ty} = 130 ksi), all material for welded specimens, both 1 inch and 1/4 inch plate, was redrawn in accordance with the curve of figure 4.02. Strength values for this redrawn material are shown in table 4-2 for unwelded 1/4 inch plate material. As can be seen from these data, the actual strength values attained were slightly below the desired value of 130 ksi. This is attributed to the extreme sensitivity of the material to both tempering time and temperature in the 130 ksi yield strength range. Since the material could not be redrawn to a higher strength level, it was welded as described in section 5.3 and cut into tensile specimens in accordance with the drawing of figure 4.01 and tested. Inspection of table 4-2 will show that weld efficiencies of 96 to 100% were obtained in this material and, further that thickness of the material being joined did not influence the resulting weld efficiency. Although the results show strength levels which were below the target minimum value, since the majority of these specimens failed in the parent metal at an average strength of 125 ksi and indentical welds in the unredrawn material showed yield strength values on the order of 140 ksi, it may be seen that weld efficiencies on the order of 100 percent are attainable in this material.

It may be concluded from the work reported herein that the target minimum strength values mentioned earlier may be obtained in a fusion welded hydrofoil structure without subsequent heat treatment.

4.2 COLUMN AND BUCKLING MECHANICAL PROPERTIES

The two major factors to be considered in optimum design of structures are (1) the material being used, and (2) the configuration of the structure. In the case of tension loaded members, the solution to the problem of optimum design is simple and straightforward, since the properties of a tension member are not influenced significantly by the shape of its cross-section. For members loaded in compression, the problem requires consideration of the size and shape of the cross-section in determining the load carrying capacity of the memoer.

In the design of a hydrofoil structure which has requirements generally similar to an aircraft wing, there are three primary types of instability failure which must be considered; (1) column buckling, (2) shear buckling and (3) compression buckling.

This section of the report deals with the establishment of theoretical design curves for the selected materials which make it possible to predict accurately the maximum load intensities the pertinent structural elements will support.

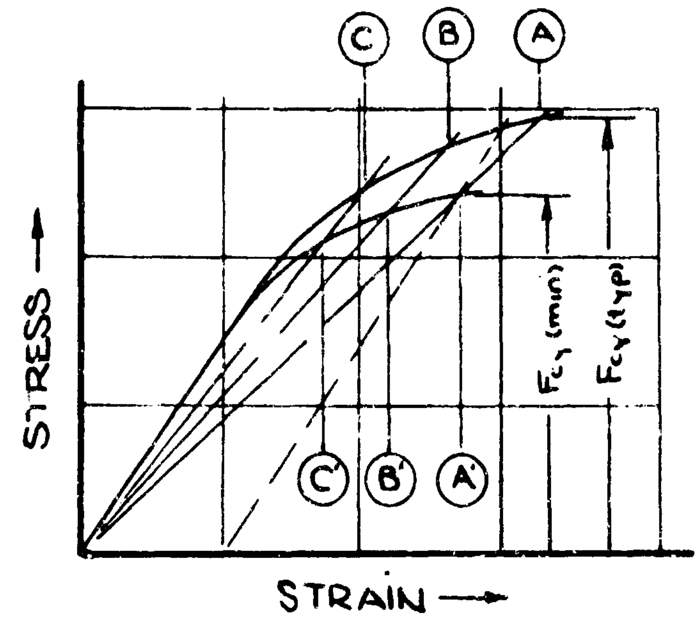
The design curves in this report are based on the approach presented by Melcon and Cozzone in Reference 17. In practice this approach uses compression stress-strain curves as input data to establish allowables based on the following general relationship:

$$\underbrace{\frac{Et}{F} = \frac{(L'/\rho)^2}{\pi^2}}_{\text{initial column buckling}} = \underbrace{\frac{(b/t)^2}{Kc}}_{\text{initial comp. buckling}} = \underbrace{\frac{(b/t)^2}{Ks}}_{\text{initial shear buckling}}$$

Development of these data requires compression stress-strain relationships which were not obtained during this program. In an effort to obtain the needed information a survey of the literature was conducted and contacts were made with the material suppliers. These efforts were only partially successfuly in obtaining these data. Data were available from Reactive Metals, Inc. on the compression stress-strain behavior of Ti-7Al-2Cb-1Ta, but nothing was found for the HY-130 steel. Unlike most titanium alloys, which demonstrate consistently higher yield values in compression, steels generally have similar stress-strain curves for both tensile and compressive loading. It was therefore decided that the use of tensile stress-strain data would produce a realistic evaluation of the stability characteristics of a structure fabricated from HY-130 steel.

The typical tensile stress-strain curve for Ti-7Al-2Cb-1Ta presented in figure 4.03 was taken from data furnished by Reactive Metals Inc. Tests were conducted on a Tinius-Olsen testing machine of 60,000 pound capacity using one-half inch diameter by two inch long specimens in accordance with ASTM standard E9-62. The specimens were loaded at a strain rate of 0.003 plus or minus 0.001 in/in/minute up to the proportional limit and at 50 pounds/minute from the proportional limit to yield. For the typical stress-strain curve for steel specimens the procedures were as outlined in section 4.1 of this report. For both materials the typical stress-strain curves were reduced to minimum guaranteed values through the use of affine transformation as described in the following paragraphs.

The following sketch will be used as a guide in describing the process of affine transformation used for generation of minimum guaranteed stress-strain curves required for this effort. For any typical curve, construct a line parallel to the initial modulus line through the 0.002 strain point to establish the typical value for yield stress. Point A' is located on this line at a stress level corresponding to the minimum guaranteed yield point (or any other value which may be required). A line drawn through the origin O and point A' will intersect the typical curve at point A as shown. For other points on the typical curve, such as points B and C, the corresponding points on the minimum curve are found as follows. Draw radial lines OB and OC. On line OB lay off OB' = OB(OA'/OA) and on line OC lay off OC' = OC(OA'/OA). The curve drawn through points A', B' and C', is the desired minimum guaranteed curve.



Typical stress-strain curves and derived minimum guaranteed curves for the Ti-7Al-2Cb-1Ta and HY-130 steel are presented in figures 4.03 and 4.04. Curves showing the column, compression and shear buckling allowables for these materials are presented in figures 4.05 and 4.06.

4.3 FATIGUE PROPERTIES

4.3.1 CORROSION FATIGUE

Until recently static strength characteristics were the deciding factor in the design of wing or foil shaped structures. Except for specialized cases such as engine mounts, rotating machinery, etc., the static margin of safety was generally sufficient to preclude fatigue problems. With the rise in use of highly efficient structural arrangements operating at high percentages of static strength allowables over extended periods of time, there has been an attendant increase in problems due to fatigue loading. Hydrofoil vehicles will be particularly susceptible to fatigue problems because (1) economic aspects dictate extremely long service life requirements, (2) high operating stress will be required in order to minimize the amount of structural weight carried by the vehicle, and (3) the marine environment causes a significant reduction in fatigue life in most materials.

For the most part, the fatigue properties of structural materials are established through the use of numerous tests conducted, in air on specimens containing notches or other discontinuities which are considered representative of those which may be found in production vehicles. Data of this type are not suitable for a hydrofoil which will spend a significant portion of its total service life operating in a corrosive media which may effect both its static and fatigue properties. Since little, if any, fatigue data of any sort are available on the selected materials, the corrosion fatigue program described in the following paragraphs was conducted during this program.

Since fusion welding is the most likely joining method envisioned for use in hydrofoil structures, all tests were conducted on welded un-notched specimens of both Ti-7Al-2Cb-1Ta and HY-130 steel. In order that the behavior of the base metal might be observed, there were no corrosion resistant coatings applied to either of the materials.

A Sonntag SF10-U axial loading fatigue machine was selected for tests in order that the specimens might be subjected to the same type of loading that the material will experience in service. This machine was then modified to permit testing in a salt water (simulated sea water) environment. The modification, which is shown in figure 4.07, consisted of the addition of a large tank to the bed of the test machine. This tank incorporated grips to pick up the lower end of the test specimen. The loading pin at the lower end of the specimen was sealed from the salt water bath to prevent premature fatigue failure of the specimen in the grip area. Provisions were made for replenishment and/or replacement of the salt water during the course of testing should it become necessary. Normal vibrations in the test machine, which operates at 1800 cpm, provided sufficient agitation in the salt water to assure that corrosion products were carried away from the surface of the specimen as rapidly as possible.

A total of 13 specimens, made in accordance with the drawing of figure 4.1, were fabricated from each of the candidate materials. These specimens were tested under uniaxial fatigue loading at a stress ratio of 0.10. Stress levels were selected to cover the range from 10^4 to 10^7 cycles of load. In order that the HY-130 specimens have a standard conditioned surface representative of a mild corrosive exposure, steel specimens were subjected to a one week static immersion in synthetic sea water prior to testing. The titanium specimens were not exposed to the sea water prior to fatigue testing since static immersion tests on all the titanium alloys indicated no detectable effects.

Subsequent to completion of each test, the specimen was removed from the test machine for inspection at the earliest opportunity. In some cases this involved a delay of up to 60 hours during which time the fracture surfaces were submerged in the salt water bath. Consequently some of the HY-130 specimens had appreciable amounts of corrosion on the fracture surfaces when inspected. Basically inspection consisted of the following items; visual examination to establish the location of the fracture followed by examination of the fracture surfaces with a ten power hand held magnifying glass to establish the presence of gross defects, if any, and the origin of fracture. Final inspection was accomplished through the use of a 30x binocular microscope for a more detailed examination of the fracture surfaces where possible. The overall condition of the specimens subsequent to testing was such that any examination of the fracture surfaces was not particularly revealing. This may be attributed to the manner in which the Sonntag fatigue machine operates. Alternating loads are applied to specimen through the use of an eccentric weight which rotates at 1800 rpm. Since there is no braking system on this machine the eccentric continues to oscillate for a short period of time after the power is cut-off by specimen failure. In most cases, this oscillation brings the fracture surfaces into violent contact with one another one or more times. This battering action then tends to obliterate all but gross details on the fracture surfaces.

The results of these tests are shown in tables 4-3 and 4-4, and are plotted in the form of S-N curves in figures 4.08 and 4.09.

As noted in tables 4-3 and 4-4, there were indications of porosity in some of the welds, but examinations of the fracture surfaces (subject to the previcusly mentioned limitations) indicated that weld quality was generally satisfactory in each material and that the fatigue failures were normal in nature.

Inspection of the S-N curves of figures 4.08 and 4.09 will show that the uncoated HY-130 is poorer in fatigue than the Ti-7Al-2Cb-1Ta as might be expected. This behavior serves to emphasize the need for application of an adequate protective system to insure structural reliability during the operating lifetime of a HY-130 hydrofoil. In order to show the degree of improvement which might be expected upon the application of a suitable protective coating to a steel hydrofoil structure, the data contained in reference 18 was extrapolated to obtain the reference curve which is shown in figure 4.09. This curve indicates that the application of a suitable protective coating might result in an increase of fatigue life as high as 20 to 1. Since conventional fatigue curves are normally considered to be independent of testing time as opposed to the effects of corrosion, which are highly time dependent, it should be noted that the data reported herein do not tell the full story. However, it may be seen that significant improvement in fatigue behavior may be expected upon application of suitable protective coatings.

Since titanium alloys have long been considered insensitive to corrosive attack (under conditions representative of those to be experienced during normal operation of hydrofoil vehicles) the curve presented in figure 4.08 was considered to be fully representative of the behavior of fusion welded Ti-7Al-2Cb-1Ta in either air or sea water. The test data generated during the course of this investigation indicate a substantial loss in fatigue life relative to ultimate tensile strength as compared to other welded titanium alloys, for example Ti-8Al-1Mo-1V as shown in reference 19 . As mentioned earlier in this discussion, examination of the fracture surfaces of these specimens by LTV personnel failed to reveal any gross abnormalities to which this loss in strength might be attributed. In an effort to obtain an explanation for this behavior, failed specimens from this group were forwarded to Reactive Metals Inc., the producer of the material, for more detailed metallurgical examination. The results of this examination revealed that there were evidences of incomplete fusion at the root of the weld. These areas would then react in much the same way as a mechanical notch with an attendant reduction in fatigue life. It should also be noted that research concerned with materials for deep submersible vehicles, reference 20 , has uncovered a previously unsuspected suscebtibility to stress-corrosion-cracking in the Ti-7Al-2Cb-1Ta material which might also contribute to the reported reduction in fatigue strength. Although this phenomena is not completely understood at the time of this writing, its effects can be readily observed as a reduction in the plane-strain fracture toughness of a given material in the presence of a flaw, such as a fatigue crack or partially welded area, and a moist environment. Since the application of a protective coating to a titanium structure is, at best, a poor and costly solution to the problem, it is felt that increased fatigue life may only be attained by using improved fabrication techniques and from metallurgical changes.

Although additional testing is recommended for both program materials to assess more thoroughly the effect of welding and/or various protective systems on overall fatigue life, the results of the tests reported herein indicate that either candidate material would be suited for use on a hydrofoil vehicle from the standpoint of fatigue behavior.

4.3.2 INTERMITTENT CORROSION - CORROSION FATIGUE

In the case of hydrofoil vehicles, additional difficulties may be encountered in designing for fatigue. These difficulties are associated with the vehicle environmental conditions. Many of the materials which are suited for use in a vehicle of this type are subject to corrosive attack when exposed to sea water. If these materials are not protected from corrosion, drastic reductions in fatigue life may be expected over a period of time.

Since a non-retractable foil may possibly spend a major portion of its service life submerged, and since the effects of static corrosion attack may interact in an unfavorable manner with those resulting from corrosion fatigue, it is mandatory that the materials used for foil construction have either a high natural resistance to corrosion or be supplied with an auxiliary protective system. This problem is not as critical for the retractable foils since they may be washed down to minimize the damaging effects of corrosion on fatigue life.

One of the promising materials for use in hydrofoil vehicles is HY-130 steel which is susceptible to corrosion attack. In order that satisfactory performance may be realized with this material, it is necessary to apply a protective coating. No known coating will provide absolute protection against sea water attack over an extended time period, and it is considered that a gradual deterioration of HY-130 steel will occur even with an intact coating. In view of this, a limited investigation was conducted to determine:

1. The effectiveness of the currently recommended protective coating in preventing corrosion attack after prolonged exposure to a marine environment.

2. The degree of interaction between the effects of static corrosion and corrosion fatigue which might be observed in the event that the coating did not afford adequate protection to the specimen.

Six unwelded-notched (Kt = 2.5) specimens fabricated from HY-130 material were coated with 20 mils of Mosite 60134A Neoprene applied over 3 mils of flame sprayed aluminum prior to testing. Three of the specimens were to be exposed to alternating periods of static immersion and fatigue cycling with three months total static immersion. The other three specimens were to be exposed and tested in a similar manner except that total immersion time was to be six months as shown in table 4-5. Specimens 2 and 3 received three months total static immersion while specimens 5 and 6 were exposed for six months. Specimens 1 and 4, which were scheduled for three and six month static immersion respectively, suffered fatigue failures prior to attaining these goals.

Subsequent to failure, all specimens were carefully inspected in order to establish the nature of the failure. Since the protective coatings did not rupture at the time of failure, inspection for evidence of corrosion was accomplished with ease. Inspections were conducted as described below:

1. The Neoprene coating was cut with a knife at the fracture location and the fracture surface was examined for signs of corrosion through the use of a 30x binocular microscope.

2. The neoprene coating was peeled back a reasonable distance on either side of the fracture and the exposed surfaces were examined for corrosion, or other abnormalities, with the 30x binocular microscope.

As previously noted, detailed inspection of the fracture surfaces was not always possible due to their battered condition, but, in most cases, the origin of fracture could be determined and the presence of corrosion products could have been detected.

Fatigue tests were conducted on the modified Sonntag SF10-U fatigue machine which is discussed in Section 4.[illegible] of this report. Test stress levels were established through the use of an S-N curve which was constructed from available information on the fatigue behavior of alloy steel (SAE 4130) tested in air. A stress level of 50,000 psi was selected to produce a life of approximately 10^6 cycles assuming no detrimental effects due to corrosion.

The tests were conducted in the following manner:

1. Soak coated specimens in sea water for predetermined periods of time (one month or two months). This exposure to be made at Harbor Island.

2. Ship wet to LTV for fatigue cycling.

3. Cycle for 3.5×10^5 cycles in simulated sea water at a maximum axial stress of 50 ksi, $R = 0.10$.

4. Ship wet to Harbor Island for an additional period of static immersion.

5. Repeat steps 1, 2, and 3 two more times, except cycle to failure during third fatigue cycling period.

Test results are presented in table 4-5 and figure 4.10. After testing was completed all specimens were carefully examined and, with the exception of specimen number 1 discussed earlier, were found to have experienced normal fatigue failures. Neither the flame sprayed aluminum nor the HY-130 base metal showed any signs of corrosion. In addition, the scatter observed in these tests is consistent with that observed in most fatigue tests and cannot be attributed to any abnormal behavior.

It may be concluded from these results that the protective coating used for this investigation provided sufficient protection to prevent base metal corrosion and fatigue life deterioration for a period of at least six months. This is not to say, however, that detrimental effects may not be observed after longer periods of exposure. Before coating lives can be extended beyond present capabilities, it will be necessary to conduct additional investigations of this nature covering significantly longer exposure periods in order to assure structural integrity for the life of the vehicle.

4.4 IMPACT TOUGHNESS

During the Phase II screening tests toughness evaluations were made on the basis of percent elongation from tensile tests, Charpy V notch tests, Nil-ductility-transition tests, weld bend tests and notched-to-unnotched ratio tensile tests. These tests were adequate for the early comparisons; however, as the program progressed, toughness deficiencies became apparent in most of the candidate materials and the more sophisticated toughness test techniques and criteria became necessary. Toward the end of Phase II, toughness data became available on a number of structural materials from the NRL drop weight tear tests, the explosion bulge test and the explosion tear tests, reference 11.

There is no established design procedure for direct relation of the impact toughness of a material to the toughness requirements of a structural component such as a hydrofoil. A measure of relation has been achieved by laboratory correlations of a large number of field service failures ranging from Liberty ships to pressure vessels. A large variety of laboratory test techniques have been developed and are used to determine the relative toughness of structural materials. The results of these tests are applied to new designs mostly by design intuition and comparisons with previous experience with similar structures. In the hydrofoil materials program, materials were tested for impact toughness using the classic Charpy V notch test and the NRL drop weight tear test over a temperature range that is expected to bracket any hydrofoil operation. The required toughness level for titanium was tentatively established at 35 foot pounds at 32°F for the Charpy V notch test. Minimum toughness requirements, as measured by the NRL drop weight tear test, have been established at 2000 foot pounds for titanium and 3000 foot pounds for steel at 32°F. These values were based on a large number of explosion tear tests conducted by NRL on hull plate materials to simulate depth charge blasts on submarines.

In the selection of alloys for this program, initial toughness goals were outlined by BuShips technical areas. These initial values were based on the background of the Navy in increasing reliability of ship and submarine structures by a toughness requirement for materials of construction both in the welded and unwelded condition, particularly in the presence of a flaw. By comparison, toughness has not been a major factor in the design of aircraft components; however, increasing numbers of brittle failures occurring in high strength load bearing components have caused changes in some designs. In this case, when toughness in the parent material and weld areas can be increased to acceptable limits by heat treating the entire structure to an acceptable lower strength level, this action has been taken. In other cases of aircraft landing gear where weight was extremely critical, the higher strength materials have been retained. In these cases, manufacturers have paid the price of the more careful processing that is required for reliable performance.

These two examples of material and heat treatment selection are briefly mentioned here because they represent extremes between which hydrofoils and struts are logical intermediate cases. They represent the intermediate position by way of the importance of weight to performance, the probability of encountering major impacts, and the consequences of brittle fracture. For brittle fracture, however, the consequences may be no worse than for the landing gear example, reference 12.

Many of the candidate hydrofoil materials were eliminated from the program because of deficient toughness. In most materials the impact toughness is an inverse function of the yield and tensile strengths and, consequently, where strength levels can be controlled by heat treatment, there is a corresponding toughness control. The strength-toughness relationship differs substantially for different materials and even for different alloy compositions of similar materials. Ti 7Al-2Cb-1Ta and Ti 8Al-2Cb-1Ta are the only titanium alloys investigated in the hydrofoil materials program which met the minimum toughness requirement. Ti 6Al-4V (ELI) with a special anneal at the beta transus temperature gave 22-24 foot pounds Charpy V notch which is a significant toughness improvement; however, comparison with NRL data indicates that the 2000 foot pound drop weight tear test requirement would not be met. In all cases, the weld toughness for titanium alloys was at least as high as that of the parent material.

4.4.1 HY 130 STEEL TOUGHNESS

HY 130 was the only steel tested in the program which provided adequate toughness. Here, also, the weld toughness equalled that of the parent material.

The results of the toughness tests for the two final selection materials are shown in Tables 4-6 and 4-7 and Figure 4-11.

The NRL toughness evaluation techniques had provided toughness substantiation for HY 80 and HY 100. Since these materials were both in use for the fabrication of the PC(H)-1 and the AGE(H)-1 foil structures, BuShips technical personnel requested that final evaluation for steel in this program be made on a higher heat treat condition of the same material. Available data for HY 80 and HY 100 steel indicated this material should have adequate toughness and stress corrosion resistance through the 130-150 KSI yield strength range.

Metallurgically, except in the brittle temper range, lower strength levels resulted in increased reliability through greater ductility, notch toughness, and greater resistance to brittle failure. HY 130 alloy heat treatment was selected to preclude stress corrosion cracking in the heat affected zone, and provide sufficient toughness to withstand severe impact without brittle failure.

This plate was given a high degree of cross-rolling (one to one) shown by Puzak and Loyd of NRL (Reference 13) to develop improved toughness in the weak direction. This cross rolling, chemistry and heat treatment resulted in toughness values considerably higher than expected for this combination on the welded or unwelded condition as shown by comparison with values listed in figure 16 of reference 14.

4.4.2 Ti 7Al-2Cb-1Ta TOUGHNESS

Toughness, strength and reliability have influenced the evaluation of titanium in the same manner as steels. Initially a low-interstitial Ti-6Al-4V was considered the best compromise material. Since stress corrosion cracking was considered an unlikely occurrence in a marine environment, only impact toughness and its relation to reliability were given consideration. The NDT test corresponding to a five to seven percent strain before fracture in the explosion bulge test was used as the desirable value which only the Ti-7Al-2Cb-1Ta alloy of the presently developed Titanium alloys could meet. This essentially embraced the reliability requirements of a submarine application, and this need justified the introduction of a new alloy into a relatively new and severe application. At this time the pertinent question of results of impact on the safety of the craft was asked. This is, "Is it better to have a strut and foil break free completely from the hull structure or have it severely deforemed so that control may be impaired?" This question, as the toughness criteria in general, leaves many unknowns to ponder. It is believed that future designs will take advantage of higher mechanical properties and proved corrosion resistance with a lower toughness requirement, while maintaining or improving reliability.

Titanium toughness data are presented in Tables 4-6, 4-7 and 4-8 and Figure 4.12. Toughness data for Ti 6Al-4V are presented to show the increased toughness that can be obtained in this material when a near-beta-transus heat treatment is employed. The Charpy V notch values shown represent approximately 50% increase in impact fracture energy over that for the "as received" toughness.

4.5 CORROSION, CAVITATION, EROSION DESIGN INFORMATION FOR SEA WATER ENVIRONMENT

This section is intended to give the designer general guidelines and data to aid in decisions in minimizing metal losses resulting from corrosion, cavitation, and erosion and to estimate skin thickness necessary to compensate for losses due to these factors.

4.5.1 SUBMERGED STATIC CORROSION

Static corrosion metal loss rates are given for a number of materials in Tables 2-9 through 2-15 and Figure 2.1, Appendix A. These rates can be used to estimate the loss in thickness in inches per year, ipy, or mils per year, mpy, (1 mil = 0.001 inches) for the periods of time that the unprotected foil is submerged either at dockside or during hullborne operation at low operating speeds. These values can also be used to estimate corrosion rates of the foils in the retracted position. This estimate would be based on the fraction of the time the foil would be wet with sea water spray. In the case of submerged times on HY-130 steel, the corrosion rate can be reduced markedly by coatings and by application of a cathodic protective system. The latter protection was not studied in this program. Titanium and titanium alloys are essentially free from any submerged static corrosion metal loss.

4.5.2 PITTING AND CREVICE CORROSION

Pitting and crevice formation is given for the materials where these phenomena were seen to occur. The HY-130 material, although not specifically tested in this program, performs generally as other low alloy steels and does not pit deeply. It shows a .007 inch average for the ten deepest pits based on data for another low alloy steel which is only .002 inches greater than the overall average of 0.005 inches per year metal loss. Titanium alloys including the Ti 6Al-4V and Ti 8Al-2Cb-1Ta do not pit or corrode preferentially at crevices. Data for other alloys evaluated in Phase II of the program are presented in Appendix A. Significant increases in corrosion rates will be noted for some materials with an increase in the temperature of the ambient sea water and the resultant increase in fouling organism population. From a design viewpoint, it is doubtful that materials which are not protected to prevent fouling, pitting or crevice corrosion, and which have a significant tendency to these effects, are practical for foils which cannot be retracted. For retractable foils, these effects must be taken into consideration in the avoidance of crevices, water traps in the retracted position and, if possible, providing for wash down of the foils when retracted. Comparative data showing the advantages to be gained by monthly removal of fouling organisms from a foil that is continuously submerged are also shown in Appendix A.

4.5.3 CAVITATION - CORROSION

Metal losses due to the combined influence of cavitation and corrosion can be seen in Tables 2-32 and 2-33, Appendix A, to be of a higher order of magnitude than for static corrosion alone. Although the exact relationships of the cavitation intensities in the magnetostricture and the rotating disc tests to those which occur on the foils at 90 knot velocities are not known, experience on the PC(H)-1 indicates that these tests are not too severe. Thus, it is apparent that the steel must be protected from low intensity cavitation and that at high cavitation levels the titanium alloys will also require protection. The use of coatings to obtain this as well as corrosion and impingement erosion corrosion protection is discussed in Section 4.7.

Assuming that the geometry of the foil and struts will generate cavitation implosion intensities equal to the NASL cavitation disc, the foils and struts manufactured from titanium alloy will be essentially free of cavitation problems at velocities up to 125 feet per second, but will reach a threshold at some velocity between 125 and 150 feet per second where major metal losses begin to occur. If the more advantageous course of design around cavitation damage cannot be taken, then the addition of elastomeric overlays in these localized areas is recommended (See Section 4.7). References 2[illegible] thru [illegible] offer a sophisticated approach to material properties to resist cavitation damage and reference 5 gives cavitation data for a large number of materials. In this program, there was a general correlation of higher hardness and good corrosion resistance with higher resistance to cavitation-corrosion damage.

4.5.4 IMPINGEMENT-EROSION

A large body of data has been generated by investigators covering the increased metal loss rates with increased sea water impingement. Many materials are shown to have a threshold for markedly increased metal loss rates at velocities below fifty feet per second. This is believed to be a function of the structure of the metal oxide and the adhesive strength of the oxide to the metal as it is formed in the marine environment. When the forces resulting from velocity and angle of impingement are great enough to remove the protective oxide, a fairly rapid reformation of the oxide follows with the resultant loss of metal and strength. The rate of oxide formation (corrosion rate) is thus seen to be a significant factor.

The impingement angle has been found to affect the degree of damage experienced on aircraft operating in rain at speeds above 500 mph. Impingement erosion of metals, coatings, and plastic laminates in this case has been found negligible at angles of impingement of less than 15 degrees to the surface. Thirty (30) day, 45° impingement angle, 90 knot sea water impingement data for steel and titanium alloys are shown in Table 2-31, Appendix A. Low alloy steels lost metal at rates greater than 0.1 inches per year of operation at 90 knots. This is 20 to 100 times the static corrosion rate and is expected to be higher as the angle of impingement increases from 45 to 90 degrees and markedly lower as the angle of impingement decreases and laminar flow is approached. Thus this increased metal loss rate requires attention for materials along leading edges and in turbulent areas. The weld areas of steel are seen to be slightly better in resistance to impingement-erosion than the parent steel and titanium alloys, welded or unwelded, are essentially immune to this effect at 90 knots.

4.5.5 STRESS CORROSION CRACKING

Time dependent brittle cracking which occurs under the influence of continuous tensile stress and a corrosive environment is commonly known as stress corrosion cracking. The most common form of stress causing these failures are those residual stresses resulting from fabrication such as welding. Since hydrofoil struts and foils will be of such size that heat treatment and stress relieving after heat treatment is impractical, testing in Phase III was done using 5 inch circular restrained welds on one foot square plates one-half and one inch thick. Thus, the parent metal, weld and heat affected zones were present as they will occur metallurgically on the foil. Exact stresses present are not known, but they are known to be high, Reference 15. Higher strength levels have generally resulted in greater susceptibility to stress corrosion cracking. Higher stress levels which exceed broad thresholds for cracking also cause a decrease in time to failure. Thirty month exposure of restrain welded HY 130 heat treated to the 145 ksi yield strength range in the 80' lot at Kure Beach indicates that it is insensitive to this effect in a marine atmosphere. As shown in Table 4-9 and Figure 4.13 the Ti 7Al-2Cb-1Ta does stress corrosion crack and thus, in its present form, is not a suitable alloy for use in this environment. Other stress corrosion data indicate the cracking of 4330M steel when stressed to ninety percent of 180 ksi yield strength and even as low as 150 ksi yield strength. Ti 6Al-4V stressed in a restrained weld specimen has shown no signs of failure to date after atmospheric and submerged exposure as shown in Table 2-29, Appendix A.

Thus, titanium alloys previously thought to be immune to stress corrosion cracking will have to be carefully tested for this phenomena. Steels heat treated above 150 ksi yield strength and exposed in the welded condition will be subject to suspicion, particularly in the heat affected zones.

4.6 CD4-MCu and 17-4PH STAINLESS STEEL CASTINGS

During Phase I and II of this program, no casting materials were investigated which proved suitable for use on operational, full size, non-retractable foils. Another possibility for casting use arose in test programs utilizing solid cast hydrofoils for hydrodynamic experiments. In this program, it was assumed that castings can be used to advantage from a structural geometry and cost standpoint. It was also assumed that the foils can be removed from the water when not in use and the relatively short life of less than 1,000 hours makes long term submerged static corrosion properties less important. Corrosion-fatigue and stress corrosion cracking tests were designed to supplement fatigue data available from the Lebanon Steel Foundry and stress corrosion cracking data from the Marine Engineering Laboratory. 17-4PH was given the H-1100 age and CD4-MCu was heat treated with a furnace cool to 1750°F to minimize quench or stress corrosion cracking.

4.6.1 CD4-MCu

CD4-MCu was tested for degradation by static corrosion, stress corrosion cracking and corrosion-fatigue. Static corrosion specimens were welded and reheat treated to simulate the practice for small foils requiring repair welds. A second weld was placed on the specimen which was not heat treated after welding to simulate minimum labor and time delay practice for use whenever this was shown to be a satisfactory repair method. Rapid pitting action up to 143 mils deep after two months static exposure indicated this material to be unsatisfactory. Static corrosion data obtained thus far are presented in Table 4-10 and Figures 4.14 and 4.15. Stress corrosion cracking tests were carried out with the standard bent beam specimens having welds both heat treated after welding and without subsequent heat treatment, stress to ninety percent of yield strength. Results shown in Table 4-10 show no cracking either submerged in sea water or in the marine atmosphere of the 80' lot at Kure Beach after a nine month exposure. These tests are being continued in order to have long term data for this chemistry and heat treatment to more completely characterize the variables which affect cracking. A more extensive stress corrosion program run by the Marine Engineering Laboratory has shown CD4-MCu to crack in several different compositions and heat treatments so that a satisfactory set of parameters to prevent cracking cannot be defined. An additional program being carried out by MEL and Ohio State University is now in progress in an effort to define these parameters. At this stage of development, the material appears to be unsatisfactory for hydrofoil use. Welding of the CD4-MCu alloy to simulate repair welds was not developed in initial trials shown in Section 5.0. Further work on this material was abandoned because of the corrosion and cracking occurring in this and the referenced MEL program.

4.6.2 17-4PH-H-1100

The 17-4PH-H-1100 casting material was tested for stress corrosion cracking, repair welding, and in corrosion-fatigue life. The stress corrosion cracking tests were run by welding the specimens as described in Section 4.6.1 for CD4-M Cu. Specimens were exposed in the unwelded, as welded, and welded and reheat-treated conditions in order to determine if stress corrosion cracking would occur in weld heat affected zones and if reheat treatment after welding were necessary to prevent HAZ cracking. Nine months exposure of these bent beam specimens exposed submerged in sea water and in the marine atmosphere has shown no failures to date. These specimens are being retained in test for further substantiation of these results.

Repair welding of this alloy presented some difficulties. Cracking during root pass welding was minimized but not completely eliminated by making a large percentage filler metal to base metal weld deposit in the root pass. Excessive warpage was reduced by alternate welding on the front and back side of the plate using the procedure shown in trial 3 on Table5-19 . This method is recommended for use when it is possible to weld on both sides of the casting or in shallow ($\frac{1}{4}$" deep) areas. Otherwise, a stress relief after welding would be desirable to minimize residual stresses.

4.6.3 CORROSION FATIGUE

Initial screening tests were conducted on unnotched, unwelded specimens fabricated from both CD4-M Cu and 17-4PH cast materials to obtain corrosion-fatigue data for comparison with earlier work done during the Phase II effort on this program, reference 2 . The specimens were tested in sea water under reversed bending conditions (rotating cantilever beam) to establish the approximate fatigue strength of 10^7 cycles. The results of these tests are presented in table4-11 . The tentative fatigue strengths obtained from these tests were 22,500 psi and 35,000 psi respectively for the CD4-M Cu and 17-4PH cast materials. The data contained in reference 2, were extrapolated to furnish a basis for comparison with these results. This extrapolation indicated that the fatigue strengths for unprotected HY-130 and 17-4PH plate would be approximately 22,500 psi and 36,500 psi respectively. It can thus be seen that the two casting alloys demonstrated fatigue lives which were comparable to those established for similar wrought materials during earlier work on this program.

As discussed previously, the CD4-M Cu cast material proved to be especially susceptible to stress-corrosion cracking in the welded condition so that further evaluation work was dropped. Additional fatigue testing was done, however, on the cast 17-4PH materials in the welded condition. Blanks were welded at LTV and shipped to Harbor Island for machining and testing in sea water. A total of four rotating beam specimens were fabricated and tested. The results of these tests are shown in Table 4-12and a tentative S-N curve is shown in Figure 4.16 . Since these tests were conducted under different types of loading and stress ratios than those reported earlier in Table 4-3, (R= -1.0 vs R= +0.10 and rotating bending vs axial loading), it was necessary to convert the data for purposes of comparison. The projected behavior of this material under axial loading conditions and a stress ratio of 0.10 is shown in Figure 4.16 as a scatter band which brackets the expected range of behavior. This was done to account for the limited amount of data to form a base for the conversion and, in addition, to compensate for possible differences in effect between bending stresses and axial stresses. Also shown in Figure 4.16 is the reference curve for HY-130 steel as reported in Figure 4.09. Inspection of this figure will show that the anticipated fatigue life for the 17-4PH steel casting is at least one order of magnitude higher than that shown for the uncoated HY-130 steel.

It may be concluded from the data reported herein that, from the standpoint of fatigue behavior only, the unprotected CD4-M Cu castings will be at least as good as the unprotected HY-130 steel plate and that the 17-4PH is decidedly superior on the same basis. It should be noted that both the CD4-M Cu and the HY-130 will probably show significant losses in fatigue strength if tested over a longer period of time when the effects of corrosion will be more pronounced. It is thus considered mandatory that these materials be supplied with a protective coating to insure fatigue life under the environment encountered by a hydrofoil vehicle. Although the fatigue life of the unprotected 17-4PH casting is not fully substantiated, it is considered a feasible material for use in castings for test vehicle foils.

4.7 COATINGS

4.7.1 COATING OPTIMIZATION

Preliminary work in this program and work by NASL, reference 5, indicate that where cavitation of significant intensity is present, hard, resinous coatings are not adequate and elastomeric coatings are required. Impingement of water at a forty-five degree angle and a ninety knot velocity, however, showed the harder, resinous coatings without resilience to be superior. Two approaches to obtain a coating system to withstand both of these effects were considered. One approach was to increase the thickness of the better cavitation resistant elastomeric coatings to permit greater energy absorption without cohesive rupture by distributing the stress across a greater number of molecular bonds. The second approach, not explored in this program, was to seek an intermediate group of properties, i.e. hardness, resilience, and elongation between the resin coatings which are resistant to the jet impingement and the elastomers which are resistant to cavitaion. It was hoped that both effects could be overcome in a coating of 20 mil thickness. This approach, explored in the Hydrofoil Coatings Program, reference 16, has not proved fruitful. This indicates that coating systems for hydrofoil craft, like coatings for aircraft should be designed for a specific hydrofoil craft and for specific areas of the foil. This approach will allow the full advantage of a variety of available coating properties to meet specific levels of cavitation, erosion, maximum velocity and submergence times.

Excellent adhesion is always a primary requirement. If the coating system will not remain firmly adhered during high performance flights after long immersions or exposure to sunlight and the temperature cycling of weather extremes, the system cannot perform its protective function. This can be seen by the adhesion failures indicated in the impingement and static corrosion test results shown in Figures 4.17 and 4.18 and Figures 2.8 and 2.9, Appendix A. Steel surfaces were found to be best prepared by grit blasting to bright metal in order to increase the available surface area to promote adhesion. In addition, selection of the primer coat, which is primarily responsible for adhesion and corrosion protection, is of extreme importance. The results of static immersion tests, Table 4-13, and sea water impingement tests, Table 4-14, indicate that Coast Pro-Seal 777P, Bostik 1007 and possibly other previously evaluated primers are moisture sensitive and thus unsuitable for use in severe marine environments. More work is needed in this area. A variation in results for coatings over a flame sprayed aluminum metal has been experienced. This area will require further work to determine what factors are causing the variations.

The succeeding layers of coating also play an important role because of their ability to limit the amount of water or ion permeation to the metal-primer interface. Each coating has a specific rate of moisture permeation dependent on formulation, method of application and thickness. These outer layers of coating also play a large role in protection from cavitation damage as previously discussed.

High speed water impingement is damaging to many coatings by tearing out small particles, in much the same manner as cavitation. It has been shown that by increasing the thickness of the Mosites 60125, bonded in place, uncured neoprene coating from 20 to 80 mils, resistance to both cavitation and impingement is obtained. This coating system can be further optimized by improving the primer peel strength which is shown in Table 413 to be reduced considerably after immersion. Damage severity at high velocities is a function of the angle of impingment as has been noted in rain erosion damage to aircraft. (See Section 4.5) Quite a number of resins have shown resistance to 90 knot sea water for a period of thirty days at an impingement angle of 45° in the Hydrofoil Coatings Program. Several elastomers have also shown this same resistance. Increasing thickness from 20 to 80 mils and hardness from Shore A 55 to Shore A 70 has improved the performance of elastomeric coating systems.

4.7.2 FOULING EFFECTS ON COATING SYSTEMS

Fouling which adheres to the foils and struts during inoperative periods is of major concern for non-retractable foils. For this reason, the question of damage to an underlying coating on a hydrofoil and strut surface due to fouling attachment and subsequent removal during high speed runs is pertinent. A test was conducted to determine if fouling attachments could be removed from a foil during the take-off run. A low alloy steel foil model for the LTV water wheel was coated with 0.080 inch on one semi-span and 0.125 inch thicknesses on the other semi-span of a cured in place Mosites 60125 neoprene rubber. The foil model was placed in a shaded location in Gulf of Mexico waters just below the tidal zone for a two month exposure during February and March. The model was transported from the Gulf to the test facility in a ceramic container of sea water and placed in test immediately while it was 75 percent covered with live barnacles. The initial test run was at 45 knots, a 3 inch depth and a negative three degree angle of attack. This angle (-3°) was chosen to obtain cavity closure on the upper surface of the foil.

Essentially all of the fouling was removed from the leading edge after a series of runs which totalled 15 minutes at 45 knots, 11 minutes at 55 knots and 12 minutes at 65 knots. No other areas of the foil surface were entirely cleaned by the above exposures which are described in Table 4.-1 These areas probably did not undergo direct water impingement due to excessive turbulence and cavitation. The barnacles that were removed were broken so that the walls of the organism were left attached to the rubber. This leads to the conclusion that at these velocities the barnacles can be destroyed leaving only a thin calcareous residue if a high angle of impingement is attained. This appears to be a fairly slow erosion process and the rate seems to be dependent on a number of contributing factors among which are the following:

a. Angle of water impingment

b. Surrounding organisms providing structural support

c. Velocity

d. Exposure time

Figure 4.20 shows the areas from which the barnacles were removed. These show up in the pictures as black areas flecked with the white bases still attached. The undamaged organisms shown may be in the areas where a cavity formed which protected them from erosion. The results indicate that (1) critical leading edges and other areas with high impingement angle may be essentially freed from organisms of this type at velocities in the range of 45 knots and (2) that coatings with cohesion and adhesion equal to or better than the 60125 neoprene will not be damaged from fouling removal by water erosion action.

4.7.3 COATING APPLICATION PROCEDURES

The coating systems described in Figures 4.17, 4.18, 4.19, 4.20, 4.21 and Tables 4-13, 4-14, 4-15 and 4-16 were applied as follows:

A. Alumina grit blast all surfaces to be coated

B. Vapor degrease*

C. Apply 3 mils flame sprayed 1100 aluminum wire*

D. Vapor degrease

* Not required for Goodyear 23-56/M-1500 zinc rich epoxy polyamide sea water impingement specimen or coated and fouled water wheel model.

E. Mosites 60125

1. Brush apply thin coat of Mosites 60125 primer and air dry 30-60 minutes.
2. Brush apply thin wet of Mosites 60125 adhesive and air dry 30-60 minutes.
3. Roll on required thickner of Mosites 60125 calendered neoprene sheet, sealing edges as required.
4. Cure 1 hour in autoclave at 310°F. and 90 psig.

F. Bostik 1007 Primer

1. Spray apply 0.5 mil wet and air dry 1 hour.

LTV VOUGHT AERONAUTICS DIVISION

G. Andrew Brown Co. M-1500 Zinc Rich Epoxy Polyamide Resin

1. Mix componets and let stand 1 hour.
2. Spray apply 3 mil coat and air dry 4 hours.

H. Goodyear 23-56

1. Spray apply 0.3 mil coats to obtain 20 mils dry film thickness allowing 15 minutes between coats.
2. Cure 10 days at room temperature.

4.8 CHEMICAL COMPOSITIONS, HEAT TREATMENTS AND VENDOR MECHANICAL PROPERTIES

Table 4-17 presents mill data obtained from vendors for the materials that were used in this program. In addition, the basic specification requirements and limitations are included in this table for reference.

LTV VOUGHT AERONAUTICS DIVISION

TABLE 4-1

RESULTS OF TENSION TESTS ON WELDED AND UNWELDED Ti 7Al-2Cb-1Ta

	Spec. No.	Type Spec.	Ftu ksi	Fty ksi	E psi x 10^6	Elong. % in 2 in	Remarks
1 Inch Thick Plate	LU-1	Unwelded	116.9	105.1	17.7	15.1	
	LU-2	Longitudinal	117.0	104.4	17.7	12.0	
	LU-3		118.4	104.2	18.7	12.3	
		Avg:	117.4	104.5	18.0	13.1	
	TU-1	Unwelded	116.8	103.8	17.4	15.1	
	TU-2	Transverse	117.9	104.6	18.3	12.3	
	TU-3		117.9	105.0	17.9	13.7	
		Avg:	117.5	104.5	17.9	13.7	
	12-1	Welded	122.4	107.5	18.0	12.0	(1)
	12-2	Transverse	118.9	105.1	17.5	10.8	(1)
	12-3		121.4	108.8	18.0	10.1	(1)
	12-4		119.8	106.0	17.9	11.5	(1)
	12-5		120.0	105.9	18.0	12.5	(1)
		Avg:	120.5	106.6	17.9	11.4	
1/4 Inch Thick Plate	19T-5	Unwelded	116.4	102.0	17.6	13.2	
	19T-6	Longitudinal	115.6	102.7	17.5	9.3	
		Avg:	116.0	102.3	17.5	11.2	
	20T-8	Unwelded	116.9	103.4	17.7	11.5	
	20T-9	Transverse	117.3	102.9	18.0	15.5	
	20T-10		117.9	103.9	17.8	11.5	
		Avg:	117.4	103.4	17.8	12.8	
	14T-1	Welded	118.5	104.8	17.2	11.1	(1)
	14T-2	Transverse	117.5	105.4	17.9	9.6	(1)
	14T-3		118.4	104.5	17.0	12.2	(1)
	14T-4		117.3	104.0	17.2	10.8	(1)
	14T-7		116.8	104.1	17.1	9.8	(1)
		Avg:	117.7	104.6	17.3	10.7	

Notes:

(1) Specimen failed outside weld area.
(2) Specimens welded as described in section 5.3.2.

LTV VOUGHT AERONAUTICS DIVISION

TABLE 4-2

RESULTS OF TENSION TESTS ON WELDED AND UNWELDED HY-130

	Spec. No.	Type Spec.	F_{tu} ksi	F_{ty} ksi	E psi x 10^6	Elong. % in 2 in	Remarks
1 Inch Thick Plate	UL-1	Unwelded	147.2	138.7	30.6	14.9	
	UL-2	Longitudinal	144.8	136.8	28.8	14.5	
	UL-3	(4)	147.1	134.1	28.2	14.8	
		Avg:	146.3	136.5	29.2	14.7	
	UT-1	Unwelded	147.5	139.7	28.5	14.1	
	UT-2	Transverse	146.6	139.3	29.1	12.7	
	UT-3	(4)	148.7	140.7	28.5	13.7	
		Avg:	147.6	139.9	28.7	13.5	
	1-1	Welded	132.4	123.0	27.7	12.5	(2)
	1-3	Transverse	133.3	123.0	29.7	9.5	(2)
	2-1	(5)	134.6	124.5	29.6	9.5	(2)
	2-2		132.6	122.0	29.4	10.7	(2)
	59-1		131.5	124.7	26.0	6.8	
	59-2		130.6	123.0	29.1	6.9	
	59-3		135.5	123.3	27.9	10.0	(2)
	59-4		134.2	124.5	30.1	10.0	(2)
	59-5		138.9	128.0	29.5	[illegible]	(2)
	59-6		133.7	124.3	29.8	8.6	
		Avg:	133.7	124.0	29.1	9.5	
	22-1	Welded	118.8	114.0	27.8	4.6	(3)
	22-3	Transverse (1)	134.2	115.4	31.0	10.6	
		Avg:	126.5	114.7	29.4	7.5	
1/4 Inch Thick Plate	2SL-4	Unwelded	137.7	128.6	28.0	10.7	
	2SL-5	Longitudinal	136.9	130.2	29.5	10.3	
	2SL-6	(5)	138.6	130.0	28.0	11.1	
		Avg:	137.7	129.6	28.5	10.7	
	1ST-1	Unwelded	137.4	127.9	28.4	12.1	
	1ST-2	Transverse	[illegible]	131.6	28.1	10.2	
	1ST-3	(5)	138.8	129.1	29.0	11.0	
		Avg:	137.9	129.5	28.5	11.1	

LTV VOUGHT AERONAUTICS DIVISION

TABLE 4-2 (CONCLUDED)

	Spec. No.	Type Spec.	F_{tu} ksi	F_{ty} ksi	E psi x 10^6	Elong % in 2 in	Remarks
1/4 Inch Thick Plate	15SW-9	Welded	134.1	122.8	28.6	8.3	(2)
	15SW-10	Transverse	135.1	124.4	28.0	9.0	(2)
	15SW-11	(5)	135.6	124.1	28.6	9.3	(2)
	15SW-7		134.4	123.9	28.0	10.7	(2)
	15SW-8		136.6	126.4	29.2	9.6	(2)
		Avg.	135.2	124.3	28.5	9.4	

Notes:

(1) Hand welded specimen blanks.

(2) Failed away from weld.

(3) Weld contained flaws (cracks).

(4) As received "high strength" meterial

(5) Redrawn to lower strength levels.

(6) Specimens welded as described in section 5.3.1.

SUPPLEMENTARY WELD STRENGTH DATA

(Ref. Section 5.3.1)

1 inch thick HY-130 welded with Linde [illegible] wire

No	Ftu Ksi	Fty Ksi	Elong % in 2 in	Remarks
1	145.7	140.5	4.0	10 to [illegible],000 joules/in
2	144.4	140.3	3.5	[illegible]°F interpass temperature

Notes:

(1) 1/2 inch round by 2 inch gage length specimens.
(2) All specimens failed in weld.

TABLE 4-3

HY-130 CORROSION FATIGUE TEST RESULTS

Axial Loading R = 0.10

Spec. No.	f max	Cycles	Remarks
SF-1	75,000	7,000	Slight porosity in weld.
SF-2	62,000	67,000	Slight porosity in weld.
SF-3	45,000	382,000	Normal.
SF-4	62,000	49,000	Normal.
SF-7	75,000	32,000	Normal.
SF-5	25,000	10,335,000	No failure.
SF-6	62,000	52,000	Normal.
SF-8	32,000	376,000	Normal.
SF-9	75,000	261,000	Large void in weld.
SF-10	45,000	408,000	Normal.
SF-11	45,000	307,000	Normal.
SF-12	32,000	405,000	Slight porosity in weld
SF-13	32,000	3,120,000	Failed away from weld.

Notes:

(1) All specimens soaked in salt water seven days prior to test.

(2) Specimens welded as described in Section 5.3.

LTV VOUGHT AERONAUTICS DIVISION

TABLE 4-4

Ti 7Al-2Cb-1Ta CORROSION FATIGUE TEST RESULTS

Axial Loading R = 0.10

Spec. No.	f max	Cycles	Remarks
T11-1	45,000	100,000	Failed away from weld.
T11-2	38,000	46,000	Slight porosity in weld.
T11-3	38,000	9,774,000	Normal.
T11-4	41,000	350,000	Normal.
T11-5	41,000	59,000	Normal.
T11-6	45,000	218,000	Normal.
T13-1	52,000	78,000	Normal.
T13-2	52,000	52,000	Normal.
T13-3	38,000	429,000	Normal.
T13-5	45,000	302,000	Normal.
T13-6	52,000	33,000	Normal
T13-7	38,000	990,000	Slight porosity in weld.
T13-4	41,000	7,834,000	Failed away from weld.

Note:

(1) Specimens welded as described in Section 5.3

LTV VOUGHT AERONAUTICS DIVISION

TABLE 4-5

RESULTS OF INTERMITTENT CORROSION - CORROSION FATIGUE TESTS
(COATED HY-130 STEEL)

Spec. No.	Immersion Period	No. of Immersions	Immersion Time-Total	Cycles to Failure	Remarks
1	1 mo.	1	1 mo.	200,000	(1)(3)
2	1 mo.	3	3 mo.	736,000	(2)
3	1 mo.	3	3 mo.	903,000	(2)
4	2 mo.	2	4 mo.	614,000	(2)(3)
5	2 mo.	3	6 mo.	806,000	(2)
6	2 mo.	3	6 mo.	2,320,000	(2)

Notes:

(1) Indications of pre-test damage to specimen.

(2) Inspection indicates normal fatigue failure with no evidence of corrosion.

(3) Specimen failed prior to attaining desired total immersion time.

TABLE 4-6

IMPACT TOUGHNESS DATA

DATA FROM	MATERIAL THICKNESS (IN)	HY 100 CHARPY V NOTCH RESULTS (FT.-LB.) TEST TEMPERATURE (°F) 0	32	65	100	HY 100 GRAIN OR WELD DIRECTION	HY 100 F_{ty} (KSI)	TI 7AL-2Cb-1Ta CHARPY V NOTCH RESULTS (FT.-LB.) TEST TEMPERATURE (°F) -80	0	32	65	100	TI GRAIN OR WELD DIRECTION	TI F_{ty} (KSI)	HEAT NO.
RMI[1]	1.0	---	---	---	---	---	---	---	---	---	44.5 U[2]	---	---	102 U	291479
	0.250	---	---	---	---	---	---	28 U	---	---	---	---	---	102 U	291303
	0.353	---	---	---	---	---	---	---	---	---	26.5 U	---	---	113 U	291476
	0.500	---	---	---	---	---	---	28 U	---	---	---	---	---	106 U	291476
LTV	1.0	--	58 W	---	---	---	142 W	---	---	40 W	---	---	---	110 W	291479
		59 U	67 U	68 U	54 U	Long.	137 U	---	39 U	29 U	45 U	47 U	Long.	104 U	
		62	58	60	58			--	44	42	51	45			
		67	59	61	64			---	---	44	44	50			
		63	68	66	64			---	38	42	45	47	Trans.		
		64	70	70	70			---	44	40	42	50			
		67	66	70	66			---	49	50	42	45			
		64	60	62	64	Trans.	139 U	---	41 W	52 W	32 W	--- W		105 W	
		60	61	61	56			---	48	40*	35	---			
		61	62	64	63			---	16*	40	46	---			
		69	72	68	64			---	48	44	44	44			
		73	68	65	65			---	40	41	45	46			
		62	61	71	65			---	47	44	46	48			
		25* W	42 W	42* W	49* W	Trans.	135[3] W								
		35*	41	40*	57										
		56	54	40*	64										
		---	50	---	---										
		---	53	---	---										
		---	51	---	---										
		---	65	---	---										
		---	60	---	---										
		---	68	---	---										

(1) Reactive Metals, Inc. (2) U - Unwelded, W - Welded (3) Estimated strength of weld * Flaw in weld.

LTV VOUGHT AERONAUTICS DIVISION

TABLE 4-7

NRL DROP WRIGHT TEAR TEST DATA

TEST TEMPERATURE = 32° F

Ti [illegible]Al-2Cb-1Ta (Heat No. 291479)		HY 130 (Heat No. N 53023	
Condition	Energy (Ft. Lbs.)	Condition	Energy (Ft. Lbs.)
Unwelded		Unwelded	
Long.	2114	Long	4000-5000
WR	2294		
Welded		Welded	
1	2[illegible]80	1	2618
2	2900	2	2902
3	2900	HAZ	3333

Ti 6Al-4V	
Condition	Energy (Ft. Lbs.)
Unwelded	
Long	
1	900
2	1000
3	500*
WR	
1	660
Welded	
1	3096
2	1840
3	4640

* No Failure

TABLE 4-8

Ti 6Al-4V CHARPY V NOTCH TESTS

ANNEALING TEMP (°F*)	FRACTURE ENERGY (FT. LBS. @32°F)	F_{TY} (KSI)	F_{TU} (KSI)
1725	22,23	132.2	140.8
1750	23,22	137.4	140.2
1775	23,22	131.8	140.5
1800	21,22	130.4	141.5
1825	24,23	133.8	121.4
1850	19,19	134.0	141.4
1750**	30,29	105.8	126.0
1825**	24,19	106.1	127.9

* Reheat treatment by L-T-V

** Sample of Ti 6Al-4V (ELI) from Harvey Aluminum, Inc.

Composition (%)		Mechanical Properties	
Oxygen	.06	F_{TY} (KSI) .2%	112.8
Nitrogen	.06	F_{TU} (KSI)	126.0
Carbon	.025	Elong. (%)	14
Iron	.11	Red. Area (%)	36
Al	6.20		
V	4.12		
Ti	R		

TABLE 4-9

Restrained Weld Stress Data Ti 7Al-2Cb-1Ta and HY-130 (1)

Material (2)	Material Thickness (In)	Type Exposure	Results: Failure	Results: No Failure
Ti 7Al-2Cb-1Ta	1/2	80' Lot	Severe cracking after 1[illegible] days exposure See Figure 4.13	
	1	Sea Water Immersion		Exposed 12 November 1964 No failure to date
HY-130	1	Sea Water Immersion		Exposed 12 November 1964 No failure to date

(1) 5 inch diameter circular patch restrain welded in center of 12" X 12" plates per Tables 5-1, 5-14 and 5-15.

(2) Material heat treatment and composition per Table 4-17.

TABLE 4-10
STATIC CORROSION DATA CD 4 MCU (CAST)

MONTHS EXPOSED	UNWELDED SPECIMEN NO. 1 WT. LOSS (GMS)	UNWELDED SPECIMEN NO. 1 PIT DEPTH (MILS) MAX.	UNWELDED SPECIMEN NO. 1 PIT DEPTH (MILS) AVG.	UNWELDED SPECIMEN NO. 2 WT. LOSS (GMS)	UNWELDED SPECIMEN NO. 2 PIT DEPTH (MILS) MAX.	UNWELDED SPECIMEN NO. 2 PIT DEPTH (MILS) AVG.	WELDED SPECIMEN NO. 1* WT. LOSS (GMS)	WELDED SPECIMEN NO. 1* PIT DEPTH (MILS) MAX.	WELDED SPECIMEN NO. 1* PIT DEPTH (MILS) AVG.	WELDED SPECIMEN NO. 2 WT. LOSS (GMS)	WELDED SPECIMEN NO. 2 PIT DEPTH (MILS) MAX.	WELDED SPECIMEN NO. 2 PIT DEPTH (MILS) AVG.	% FOULED	AVG. WATER TEMP. (°F)
MONTHLY REMOVAL SPECIMENS														
1	3.4	92	48[1]	3.3	42	21[1,2]	2.9	125	62[3]	2.3	3/32 x 5/16 x 112 1/16 x 1/8 x 56		90	76
2	2.9	106	72[1,3]	2.9	113	73[1,3]	2.3	143	62[3]	3.1	3/32 x 7/16 x 118 Numerous others[3]		(4)	(4)
3	1.0	128	94[1,3]	0.6	142	91[1,3]	0.9	143	83[3]	1.6	132	98[3]	95	78
3*					TEST TERMINATED						TEST TERMINATED			
4	1.2	138	110[1,3]				1.1	143	84[3]				40	66
5	0.2	138	110[1,3]				0.1	144	103[3]				25	60
6	0.1	148	110[1,3]				0.2	146	103[3,5]				5	52
[illegible]	[illegible]	160	110[1,3]				0.2	146	103[3,5]				5	49
[illegible]	[illegible]	168	110[1,3]				0.0	146	103[3,5]				10	47
[illegible]	[illegible]	169	110[1,3]				0.1	146	103[3,5]				20	47
SIX MONTH CUMULATIVE TOTALS														
	[illegible]	[illegible]	110[1,3]				[illegible]	146	103[3,5]					66
SIX MONTH CONTINUOUS IMMERSION SPECIMENS														
[illegible]	[illegible]	56	30	5.0	84	70	[illegible]	108	45	2.9	Perforated. Numerous to 85		100	71

*Welded with CD - MCU filler wire. Two welds: (a) Heat treated after welding. (b) As welded.
(1) Numerous on edges. (2) Incipient on surfaces. (3) Severe on surface. (4) Not reported. (5) Crack in (b) weld.

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TABLE 4-11

RESULTS OF CORROSION FATIGUE SCREENING

TESTS ON CAST CD4-MCu and 17-4PH ALLOYS

Rotating Cantilever Beam, R= -1.0
Unwelded, K_t = 1.0

Mat'l	Spec No.	Max Stress ksi	Cycles to Failure x 10^6	Remarks
CD4-MCu	499AN02	15.0	12.281	No Failure
CD4-MCu	499AN03	20.0	12.065	No Failure
CD4-MCu	499AN04	22.5	10.090	No Failure
17-4PH	048AV01	25.0	11.858	No Failure
17-4PH	048AV02	35.0	13.785	No Failure
17-4PH	048AV04	40.0	1.524	
17-4PH	048AV03	45.0	.740	

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TABLE 4-12

RESULTS OF CORROSION FATIGUE TESTS ON

FUSION WELDED CAST 17-4PH STEEL

Rotating Beam, R= -1.0
K_t = 1.0

Spec. No.	Max. Stress ksi	Cycles to Failures x 10^6	Remarks
1	35.0	0.242	
2	30.0	0.368	
3	25.0	18.358	No Failure
4	25.0	18.240	No Failure

TABLE 4-13

SEA WATER IMMERSION DATA FOR 80 MIL MOSITES 60125 AND 20 MIL GOODYEAR 23-56 NEOPRENE COATINGS APPLIED OVER 3 MILS FLAME SPRAYED 1100 ALUMINUM ON UNWELDED HY 130 (1)

COATING SYSTEM	NO. IN TEST	COATING CONDITION SPECIMEN NO. 1	SPECIMEN NO. 2	SPECIMEN NO. 3	SPECIMEN NO. 4	% FOULED	AVG. WATER TEMP. °F
80 Mils Mosites 60125 Calendered Neoprene Sheet Over 3 Mils Flame Sprayed 1100 Aluminum Using Mosites 60125 Primer and Adhesive (2)	3 (3)	←	No Visible Deterioration		→	10	73
	6	←	No Visible Deterioration		→	100	61
	9	←	No Visible Deterioration		→	5	53
	12	←	No Visible Deterioration		→	90	51
20 Mils Goodyear 23-56 Neoprene Spray Applied Over 3 Mils Flame Sprayed 1100 Aluminum Using Bostik 1007 Primer (2)	3	4 Blisters at One Edge	1 Blister at One Corner	No Visible Defects	No Visible Defects	5	73
	6	Numerous Blisters at One Edge, One Ruptured	1 Blister at One Corner	Rust Visible at One Corner	No Visible Defects	100	61
	9	Numerous Blisters at One Edge, One Ruptured	1 Blister at One Corner	Rust Visible at One Corner	No Visible Defects	5	53
	12	Numerous Blisters at One Edge, One Ruptured	1 Blister at One Corner	Rust Visible at One Corner	No Visible Defects	100	51

(1) HY 130 Heat Treatment and Compositions per Table 4-17.

(2) Coatings applied per page [illegible].

(3) Specimens removed, cleaned, [illegible] and returned to test at 3 month intervals.

TABLE 4-14

[illegible] KNOT, [illegible], SEA WATER IMPINGEMENT DATA FOR MOSITES [illegible] AND GOODYEAR [illegible] NEOPRENE COATED HY130 STEEL (1)

COATING SYSTEM	[illegible]	TEST RESULTS (6) HOURS EXPOSED										
		[illegible]	48	110	140	158	182	280	328	448	606	719
[illegible] Mils Mosites [illegible] Neoprene Over [illegible] Mils Flame Sprayed 110C Aluminum	[illegible]	slight roughening	no change	no change	increased roughening	no change	no change	no change	no change	no change	Blister at one mounting hole	No damage at jet. Some edge lifting.
	[illegible]	slight roughening	no change	no change	1/16" dia. damage area at jet.	1/4" dia. damage area at jet.	no change	no change	no change	no change	Blistering along upper edge.	No perforation at jet. Some edge lifting.
[illegible] Mils Mosites [illegible] Neoprene Over [illegible] Mils Flame Sprayed [illegible] Aluminum	[illegible]	slight roughening	no change	no change	increased roughening	no change	no change	no change	no change	no change	1/8" dia. damage area at jet.	Slight damage at jet. Some edge lifting.
		slight roughening	no change	no change	increased roughening	no change	no change	no change	no change	no change	no change	No damage at jet. Some edge lifting.
[illegible] Mils Goodyear [illegible] Neoprene Over [illegible] Mils Flame Sprayed 110C Aluminum	[illegible]	slight roughening	no change	[illegible] dia. perforation. [illegible] lifting.	[illegible] dia. & [illegible]/4" dia. perforation. Stopped							
	[illegible]	[illegible] perforation. Stopped										
[illegible] Mils Goodyear [illegible] Neoprene Over Andrew-Brown [illegible] Zinc Rich Epoxy Polyamide Primer	[illegible]	A/5 top coat loss. ( ) Stopped										
	[illegible]	[illegible] top coat loss. ( ) Stopped										

(1) See Table [illegible] for [illegible] treatment.
(2) See Page [illegible]
(3) Average water temperature - [illegible]°F.
(4) Average water temperature - [illegible]°F.
(5) Average water temperature - [illegible]°F.
(6) See Figures [illegible]
(7) Adhesive failure of Goodyear [illegible] to Andrew-Brown Co. M-1500 zinc rich epoxy polyamide primer.

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TABLE 4-15

PHYSICAL AND MECHANICAL PROPERTIES

OF CURED MOSITES 60125 CALENDERED

NEOPRENE SHEET (1)

PROPERTY	RESULTS
Tensile Strength (PSI)	3380
Ultimate Elongation (%)	450
Hardness (Shore A)	67
Tear Strength (PLI) (2)	43.7
90° Peel Strength As Received (LB/IN) (3) (4)	Spec. 1 - 16 Spec. 2 - 27
90° Peel Strength After 10 Days In Fresh Water @ 74° F (LB/IN) (3) (4)	Spec. 1 - 10 Spec. 2 - 11

(1) 60125 neoprene cured per page 4.23. Tests performed by NASL.

(2) Per ASTM D-470-56T

(3) 60125 neoprene applied per page 4.23.

(4) Per FTMS 601, Method 8031.

TABLE 4-16

RESULTS OF WATER WHEEL FOULING REMOVAL TEST ON 80 AND 125 MIL MOSITES 60125 COATED FOIL MODEL (1)

RUN NUMBER (2)	RUNNING TIME (MINUTES)	CUMULATIVE RUNNING TIME (MINUTES)	FOIL DEPTH (INCHES)	VELOCITY (KNOTS)	ANGLE OF ATTACK (DEGREES)
1	5	5	3	45	-3
2	5	10	3	45	-3
3	5	15	6	45	-3
4	5	20	6	55	-3
5	6	26	6	55	-3
6	6	32	6	65	-3
7	6	38	6	65	-3
8	4	42	6	55	-3
9	2	44	6	55	-3
10	60	104 (3)	6	55	-3

(1) See page 4.23 for coating appl. procedures. See paragraph 4.7.2 for fouling exposure method for foil model.

(2) Fresh water used for all runs.

(3) See Figure 4.20 showing foil model after test completion.

TABLE 4-17

CHEMICAL COMPOSITIONS, HEAT TREATMENTS AND VENDOR MECHANICAL PROPERTIES

MATERIAL →	HY 130			OXWELD 84		TI 7AL-2CB-1TA			TI 6.5AL-2CB-1TA	17-4 PH		CD 4 M CU		TI 6AL-4V		TI-5AL-2.5SN
TYPE AND THICKNESS (IN) →	1.0 PLATE LADLE	1.0 PLATE TOP OF INGOT	1.0 PLATE TOP OF INGOT	WELD WIRE		1.0 PLATE	0.050 SHEET	0.250 PLATE	WELD WIRE	WELDED CASTING	UNWELDED CASTING	WELDED CASTING	UNWELDED CASTING	1.0 PLATE	1.0 PLATE	0.062 WELD WIRE
HEAT NUMBER →	← N5-023 →			R661574 SPOOL 1	R661574 SPOOL 2	291479	291476	261303	--	7127B	B6167	909D	A-4262	29844	30379	314[illegible]
ELEMENTS (%)																
C	0.18	0.18	0.17	0.15	0.100	0.0[illegible]	0.0[illegible]	0.02	0.02	0.34	0.06	0.028	0.02	0.03	0.02	0.04
Mn	0.26	0.29	0.30	1.69	1.64	0.24	0.23	---	---	0.61	0.62	0.65	0.57	---	---	0.02
P	0.009	0.008	0.006	---	---	---	---	---	---	0.015	0.019	0.019	0.027	---	--	---
S	0.008	0.008	0.00[illegible]	---	---	---	---	---	---	0.019	0.013	0.013	0.015	---	---	---
Si	0.26	0.30	0.2[illegible]	0.75	0.7[illegible]	---	0.07	---	---	0.52	0.62	0.63	0.60	---	---	---
Ni	2.83	2.67	2.70	---	---	---	---	---	---	3.87	4.10	5.62	5.70	---	---	---
Cr	1.55	1.54	1.56	---	---	---	---	---	---	15.50	16.65	26.30	26.00	---	---	---
Cu	0.07	0.06	0.06	1.04(1)	1.04(1)	---	---	---	---	2.80	2.50	2.77	2.93	---	---	---
Mo	0.45	0.47	0.47	---	0.70	---	---	---	---	---	0.09	2.00	1.97	---	---	---
V	0.02	0.002	0.002	---	---	---	---	---	---	---	---	---	---	4.1	4.1	---
Ti	0.1	0.001	0.001	---	---	R	[illegible]	R	R	---	---	---	---	R	R	R
Fe	R	R	R	R	R	0.11	0.[illegible]	0.09	0.15	R	R	R	R	0.16	0.16	0.4[illegible]
N	---	---	---	---	---	0.005	[illegible]	0.01	0.007	---	---	---	---	0.01	0.01	0.01
Al	---	---	---	---	---	[illegible]	[illegible]	[illegible]	6.3	---	---	---	---	5.0	6.2	5.2
Co	---	---	---	---	---	[illegible]	[illegible]	[illegible]	2.0	2.9	0.7	---	---	---	---	---
O	---	---	---	---	---	0.0[illegible]	[illegible]	0.07	0.07	---	---	---	---	0.13	0.12	0.1[illegible]
H	---	---	---	---	---	33 ppm	[illegible] ppm	39 ppm	15/20ppm	---	---	---	---	50/67	40/61	68/[illegible]
Ta	---	---	---	---	---	[illegible]	[illegible]	0.82	0.35	---	---	---	---	---	---	---
Sn	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.5
F_{ty} (ksi)	← 141 →			---	---	101	10[illegible]	101	---	---	136	95	93	121	122	14[illegible]
F_{tu} (ksi)	← 155 →			---	---	115	[illegible]	119	---	---	152	112	113	138	135	15[illegible]
Elong. (% in 2 in.)	← [illegible] →			---	---	1[illegible]	[illegible]	1[illegible]	---	---	12	21	25	12	14	[illegible]
R.A. (%)	← [illegible] →			---	---	[illegible]	[illegible]	[illegible]	---	---	23	43	51	---	---	---
Heat treatment →	1[illegible]°F - [illegible] hr., water quench, temper [illegible] hr. @ 10[illegible]°F			---	---	1[illegible]°F - [illegible] hr., air cool [illegible]°F - [illegible] hrs., air cool			---	Solution treat 2 hrs. @ 1950°F temper 3 hrs. @ 1100°F		2050°F - [illegible] hrs., cool 50°F/hr. to 1750°F and hold 2 hrs., oil quench		Hot rolled and annealed		Cold drawn and annealed

(1) [illegible]

FIGURE 4.01

TENSION AND AXIAL FATIGUE SPECIMEN

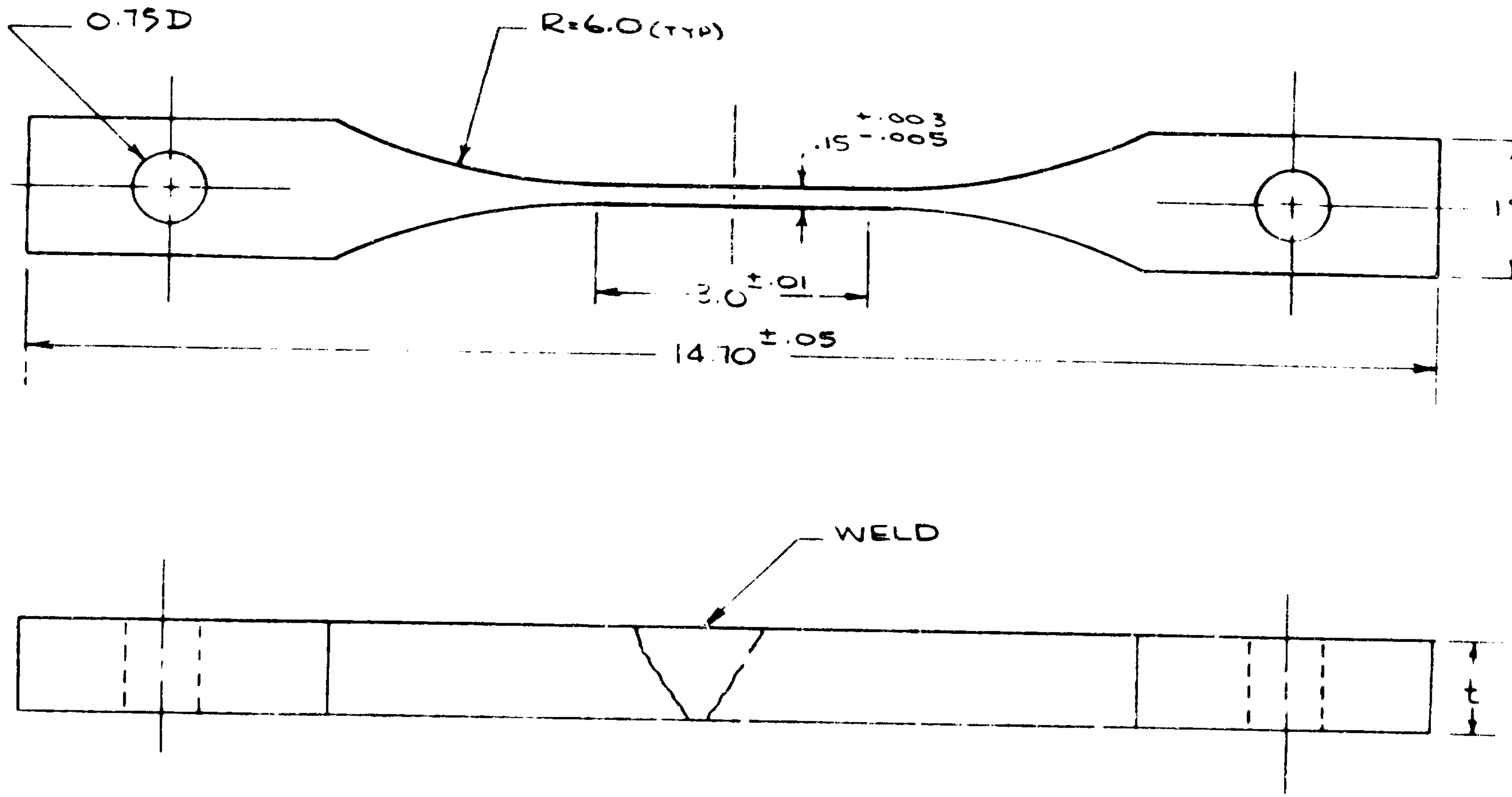


FIGURE 4.02
YIELD STRENGTH VS TEMPERING TIME
HY-130 T=1090°F

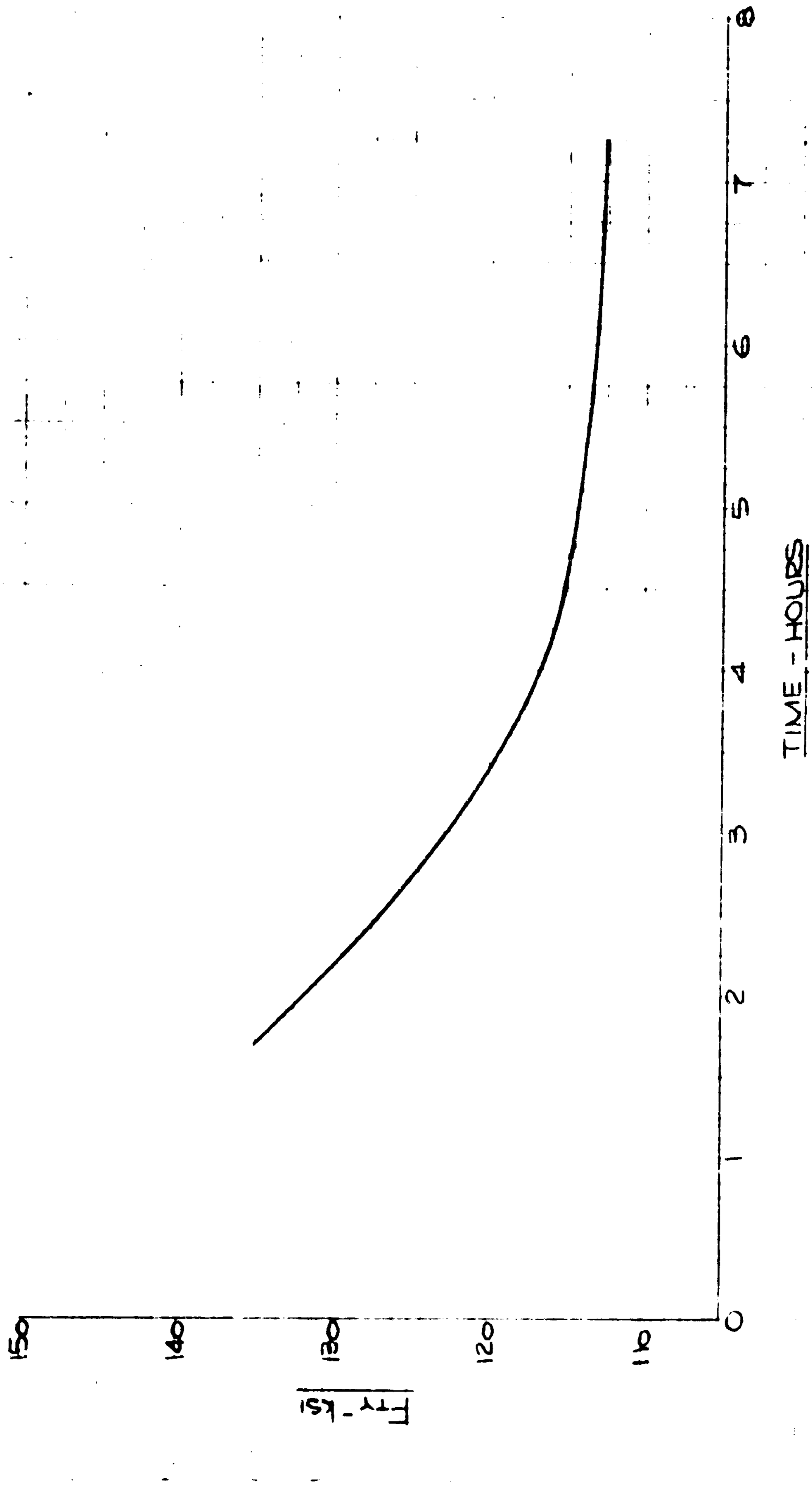


FIGURE 4.03
LONGITUDINAL STRESS - STRAIN CURVES
Ti - 7Al - 2Cb - 1Ta

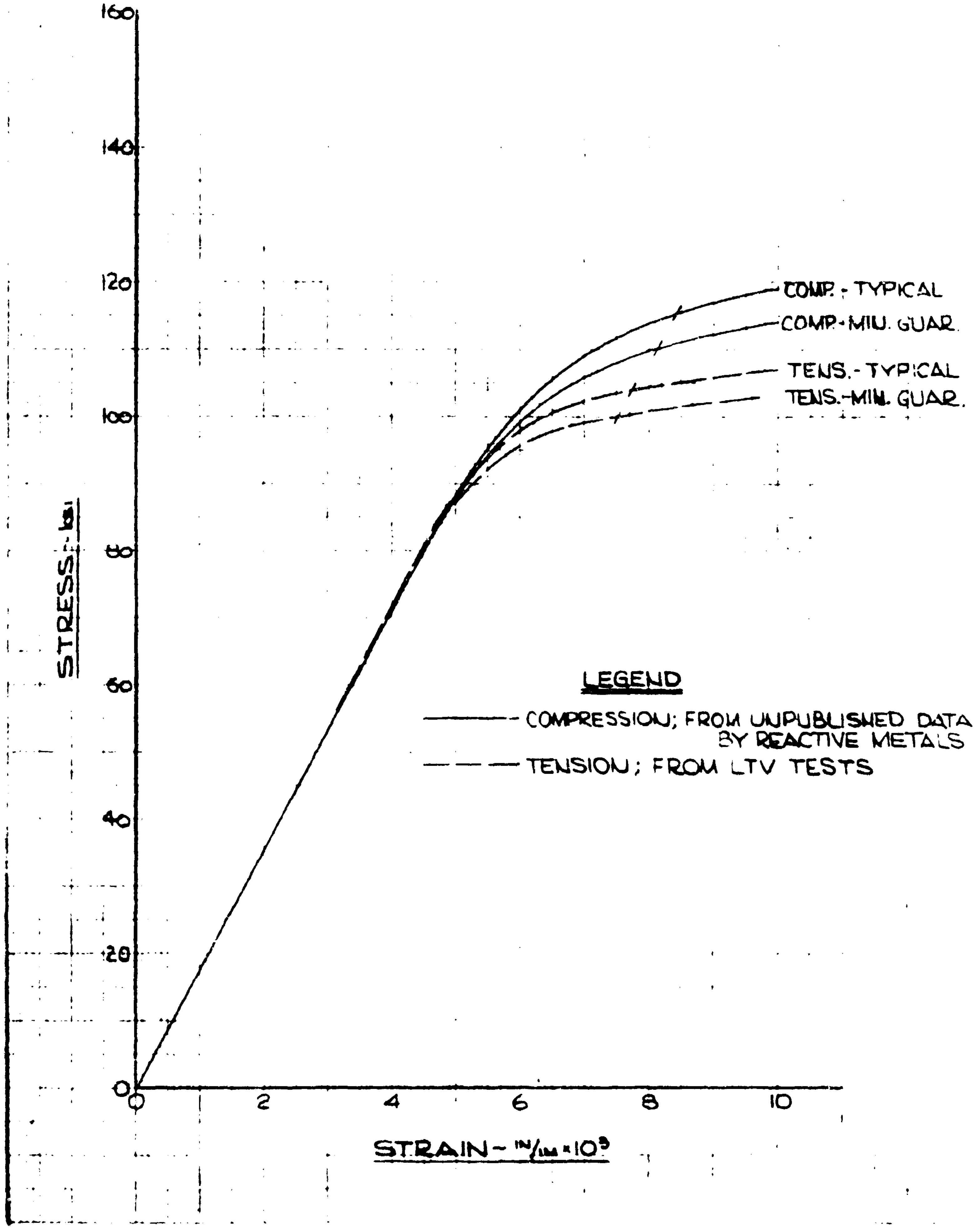


FIGURE 4.04

TENSION STRESS-STRAIN CURVES

HY-130

LONGITUDINAL

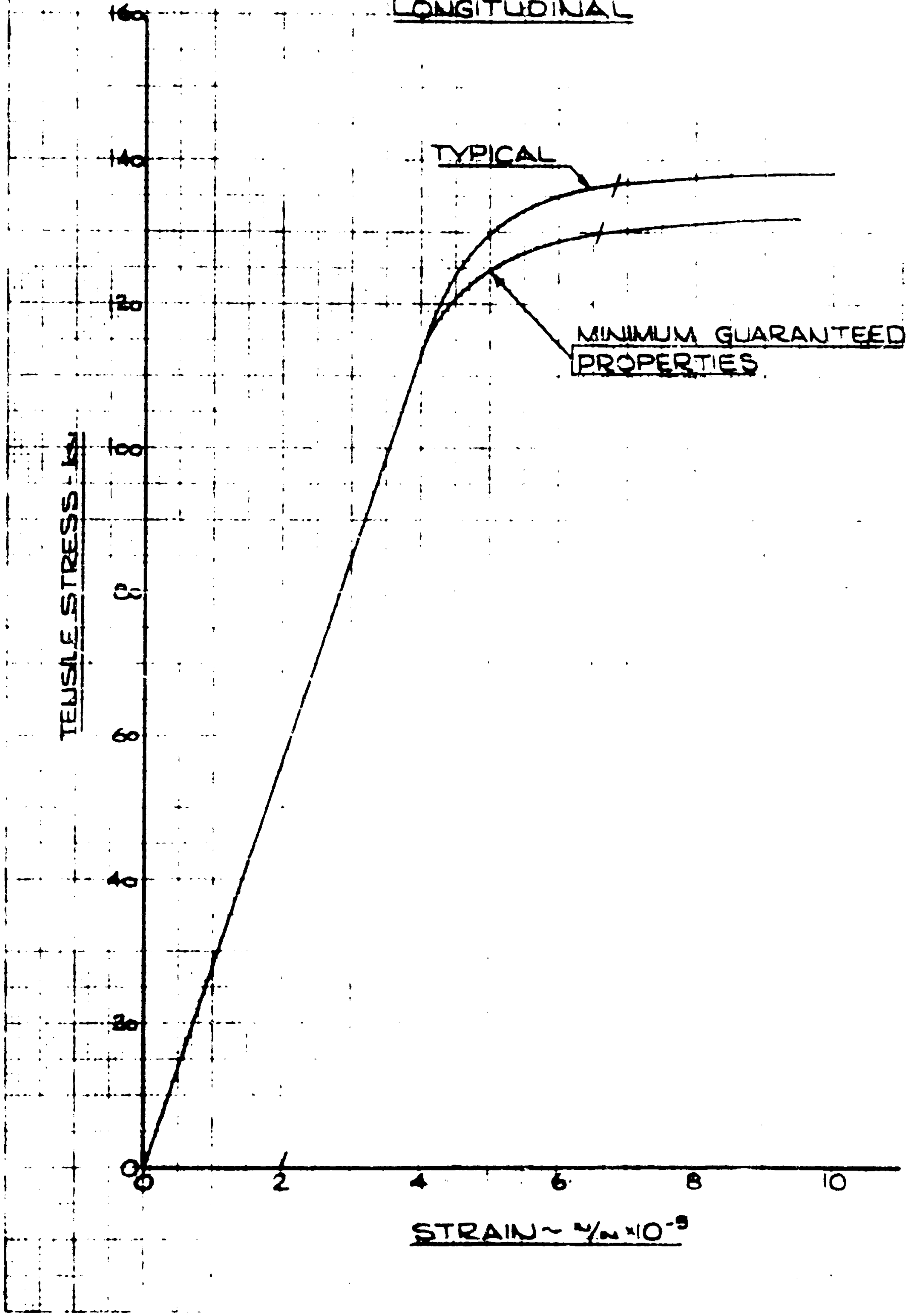


FIGURE 4.05

STABILITY CURVES

Ti-7Al-2Cb-1Ta

LONGITUDINAL

MINIMUM GUARANTEED

REF: (15)

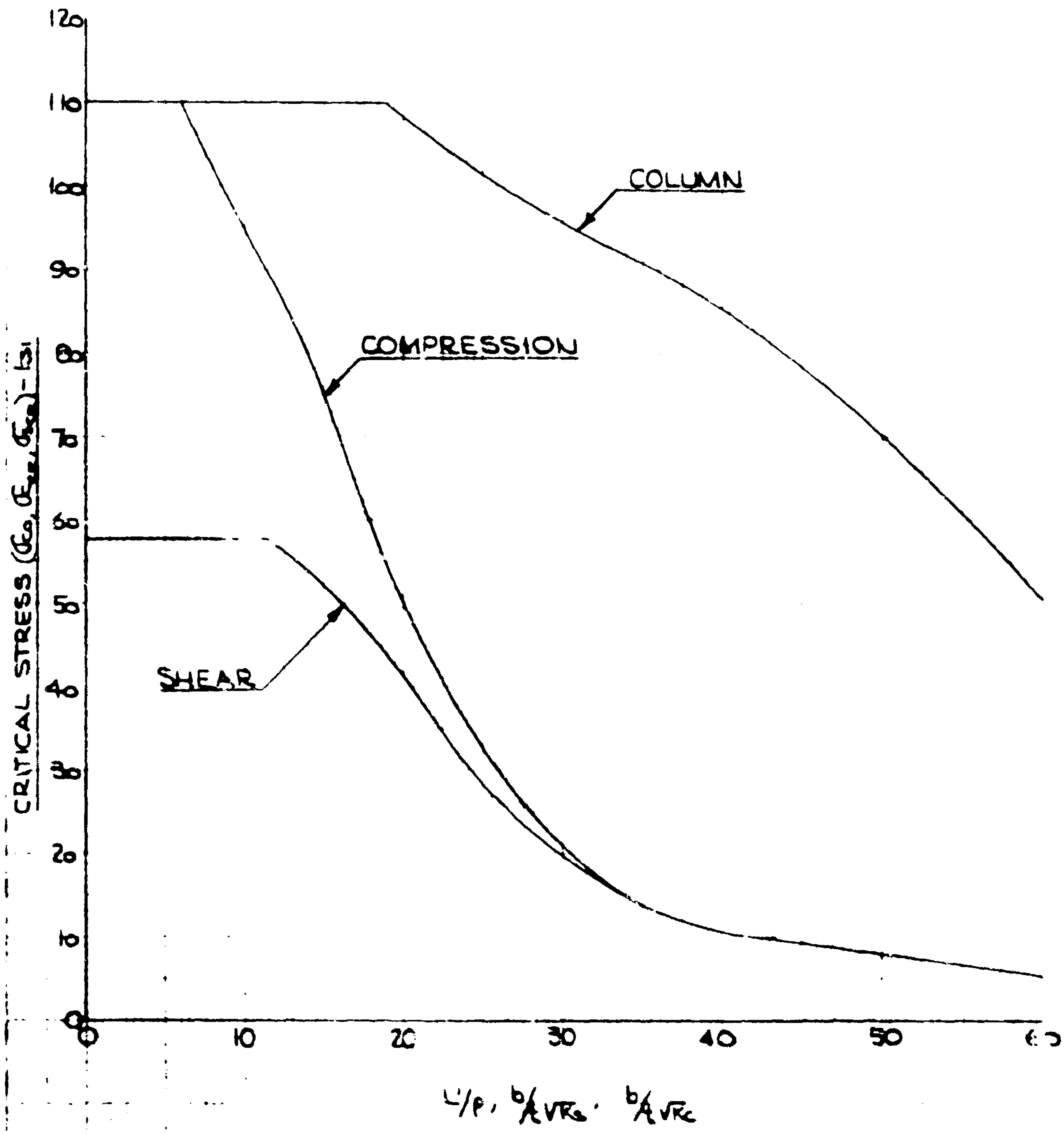


FIGURE 4.06
STABILITY CURVES
HY-130
LONGITUDINAL
MINIMUM GUARANTEED

REF (15)

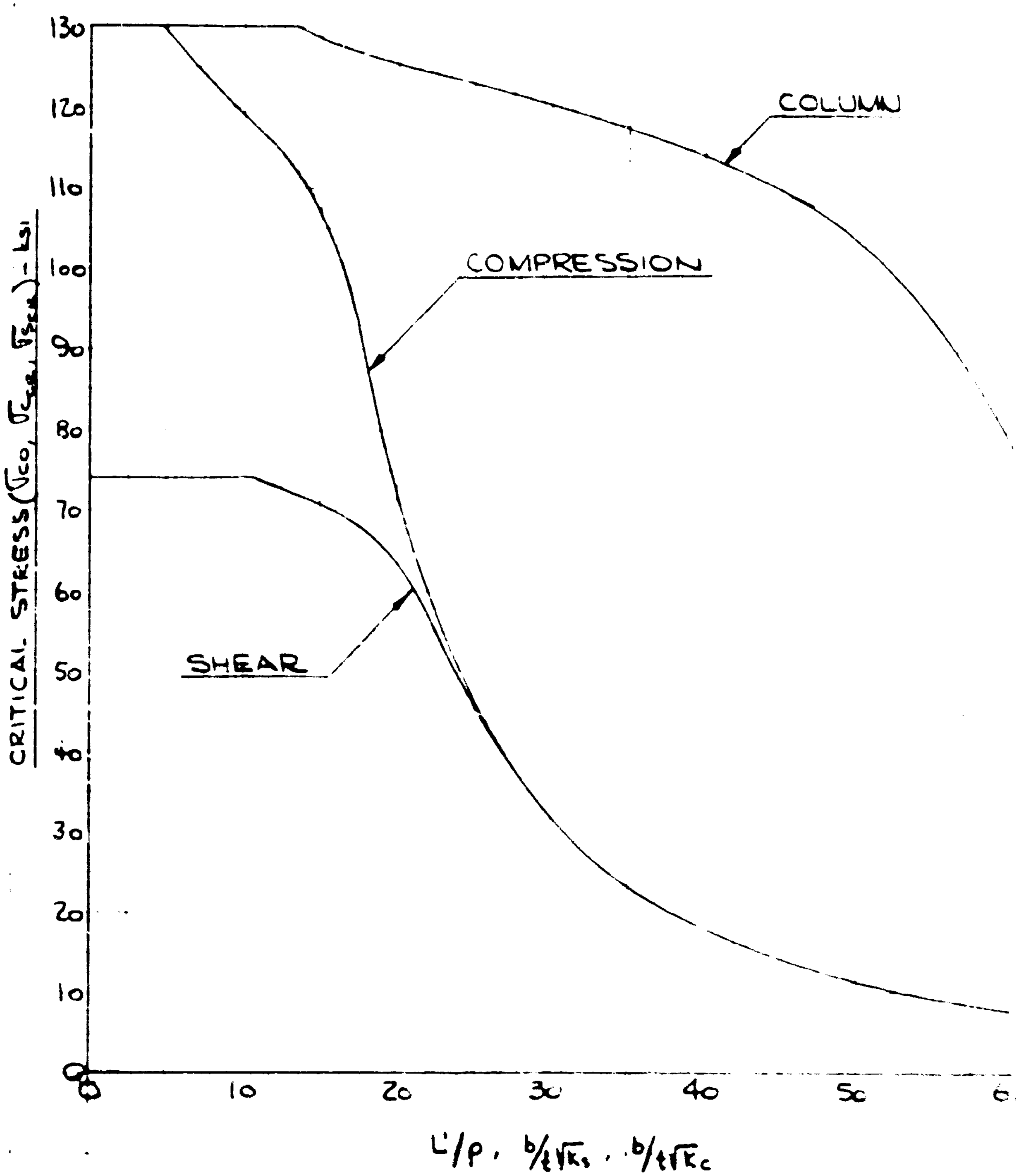
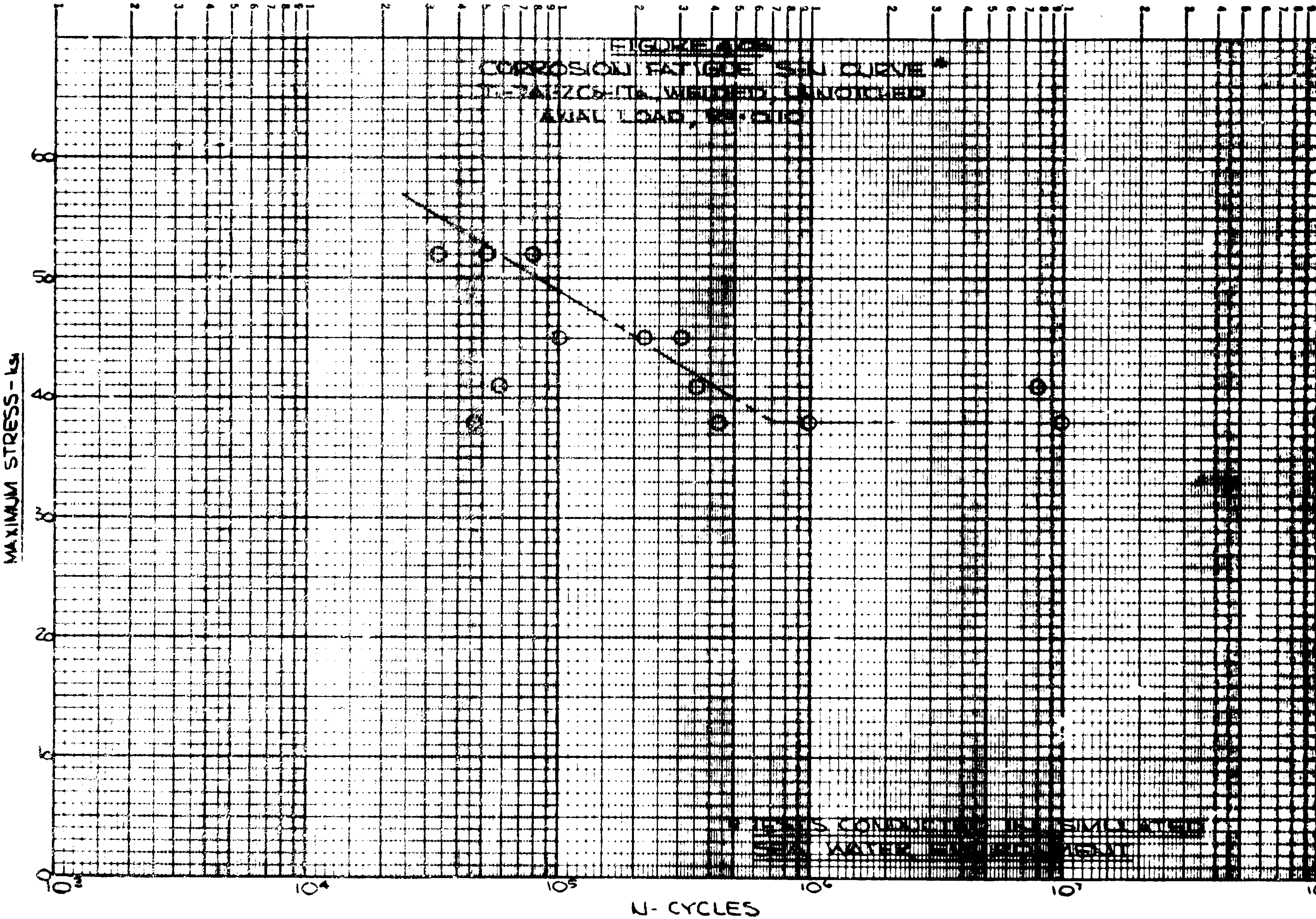


Figure 4.0[illegible] Photograph Showing Set-up for [illegible]
Fatigue Testing


CORROSION FATIGUE S-N CURVE*
AXIAL LOAD,
MAXIMUM STRESS - ksi
N - CYCLES
60
50
40
30
20
10
0
10^3
10^4
10^5
10^6
10^7
10^8

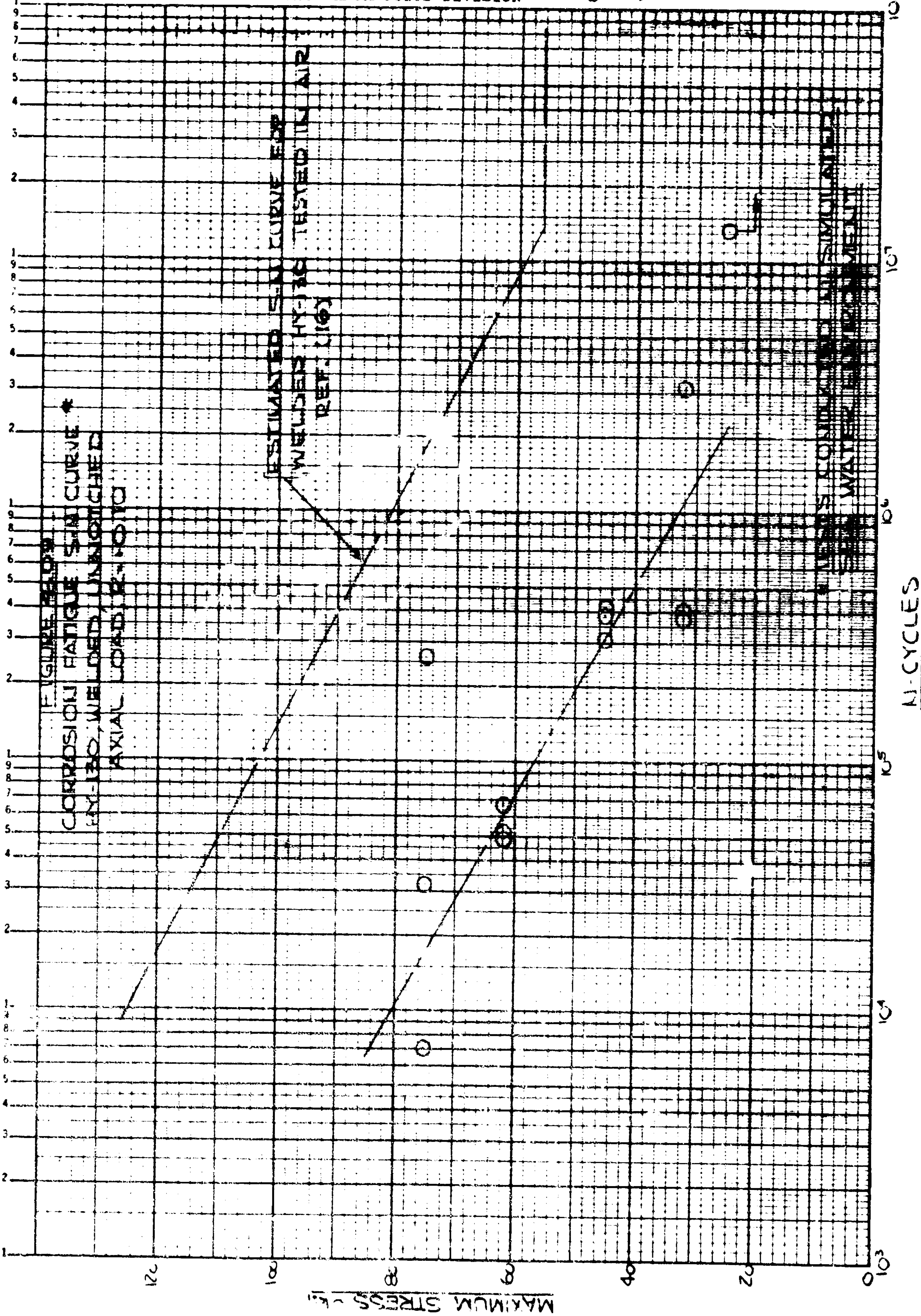


FIGURE
CORROSION FATIGUE S-N CURVE *
HY-130 WELDED, UNNOTCHED
AXIAL LOAD R=O TO
ESTIMATED S-N CURVE FOR
WELDED HY-130 TESTED IN AIR
REF. (16)
* TESTS CONDUCTED IN SIMULATED
SEA WATER ENVIRONMENT
N-CYCLES
MAXIMUM STRESS - KSI
120
100
80
60
40
20
0
10^3
10^4
10^5
10^6
10^7
10^8

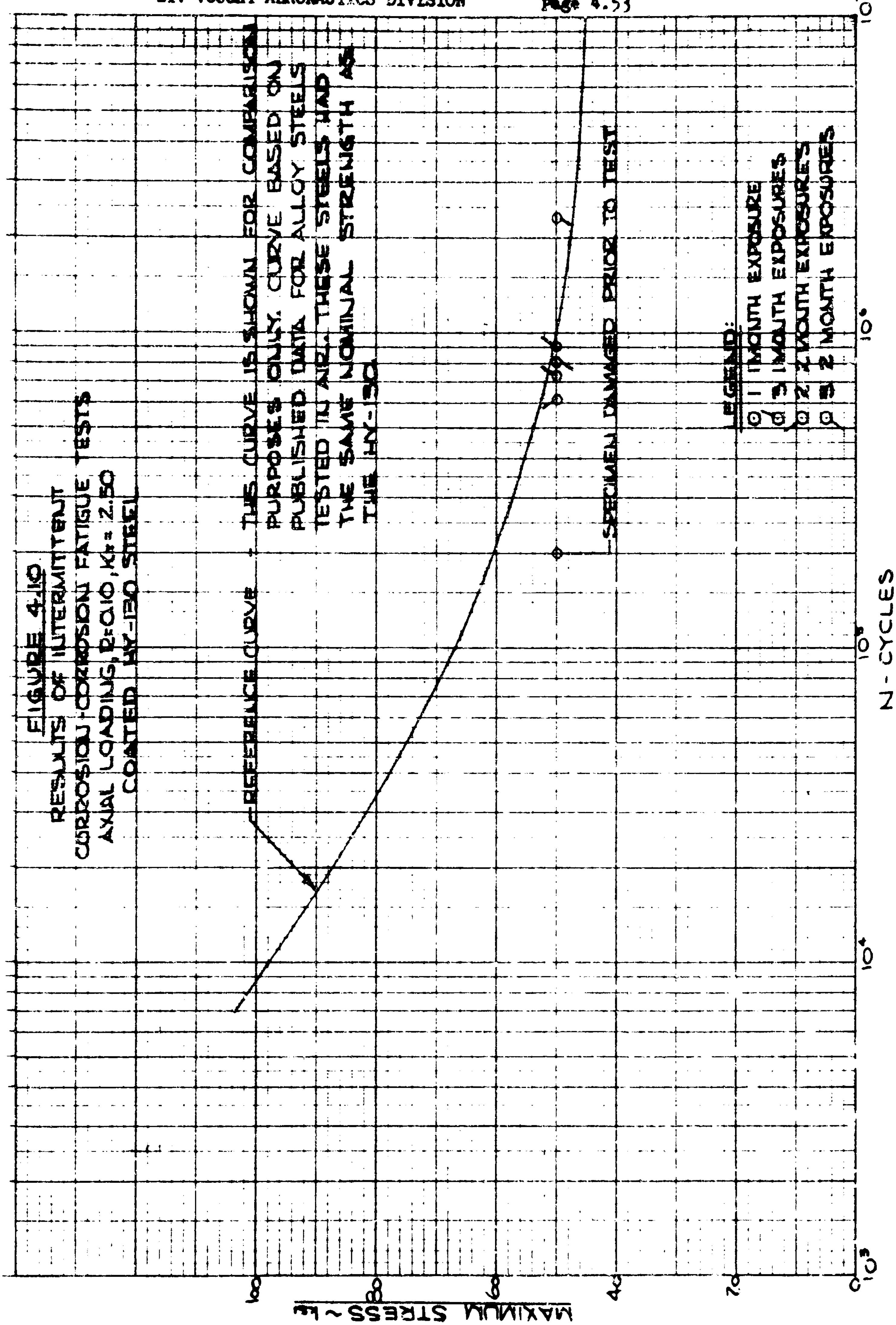
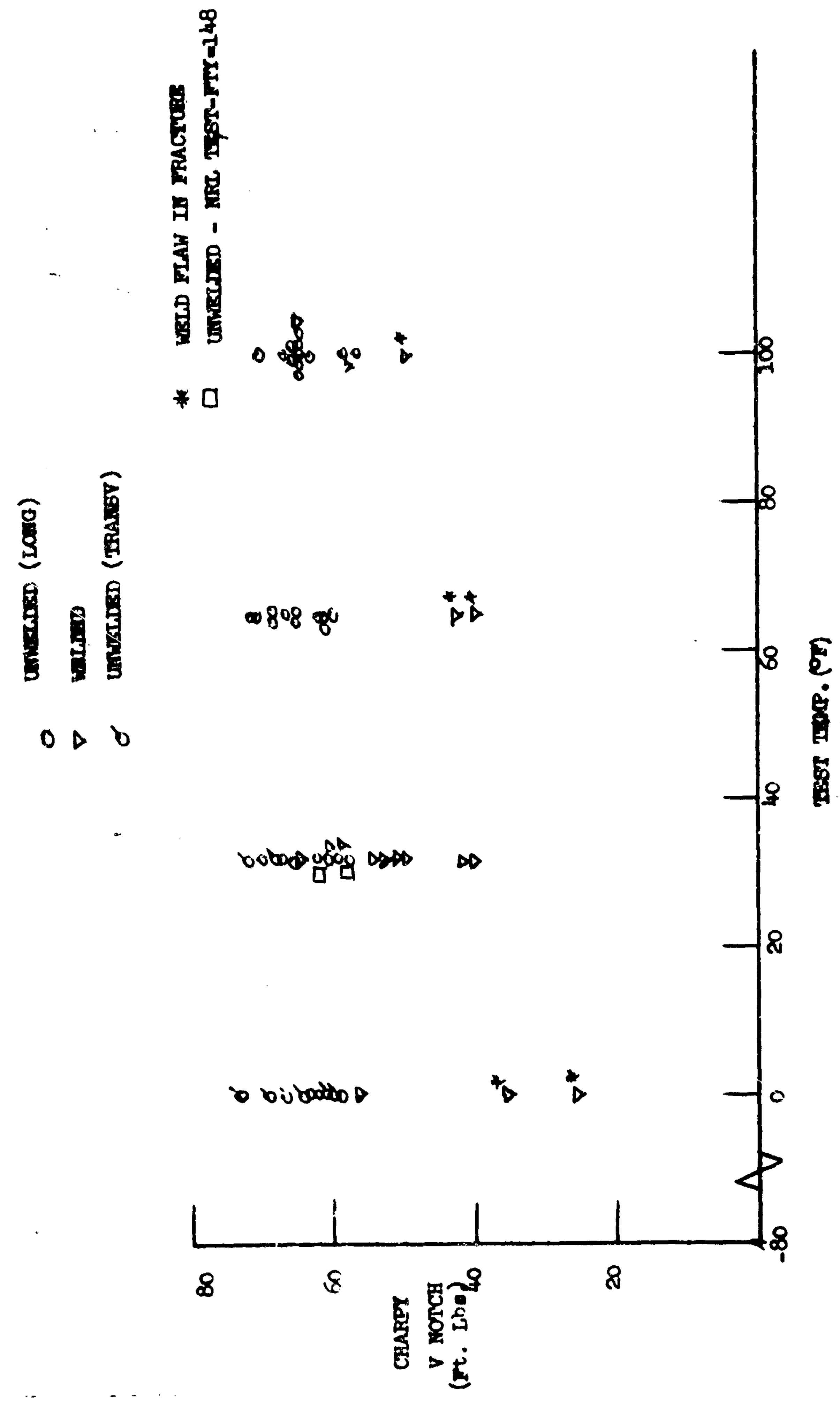


FIGURE 4.10
RESULTS OF INTERMITTENT CORROSION-CORROSION FATIGUE TESTS
AXIAL LOADING, R=0.10, K_t = 2.50
COATED HY-130 STEEL

FIGURE 4.11
HY 130 (Pty=135-139)
CHARPY V NOTCH
TOUGHNESS



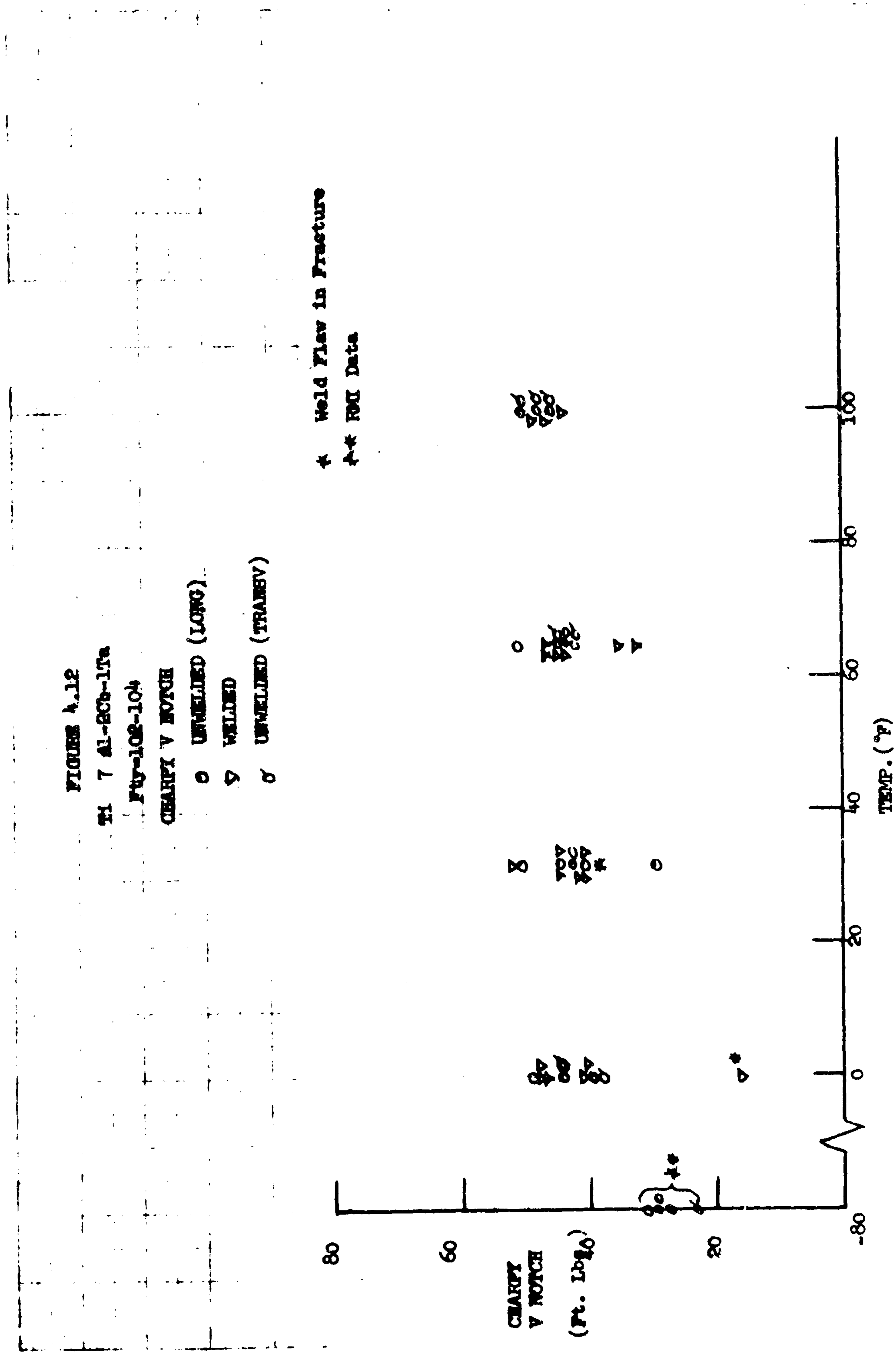


FIGURE 4.12
Ti 7 Al-2Cb-1Ta
Fty=102-104
CHARPY V NOTCH
o UNWELDED (LONG)
▽ WELDED
♂ UNWELDED (TRANSV)
* Weld Flaw in Fracture
▲* RMI Data
CHARPY V NOTCH
(Ft. Lbs.)
80
60
40
20
-80
0
20
40
60
80
100
TEMP. (°F)

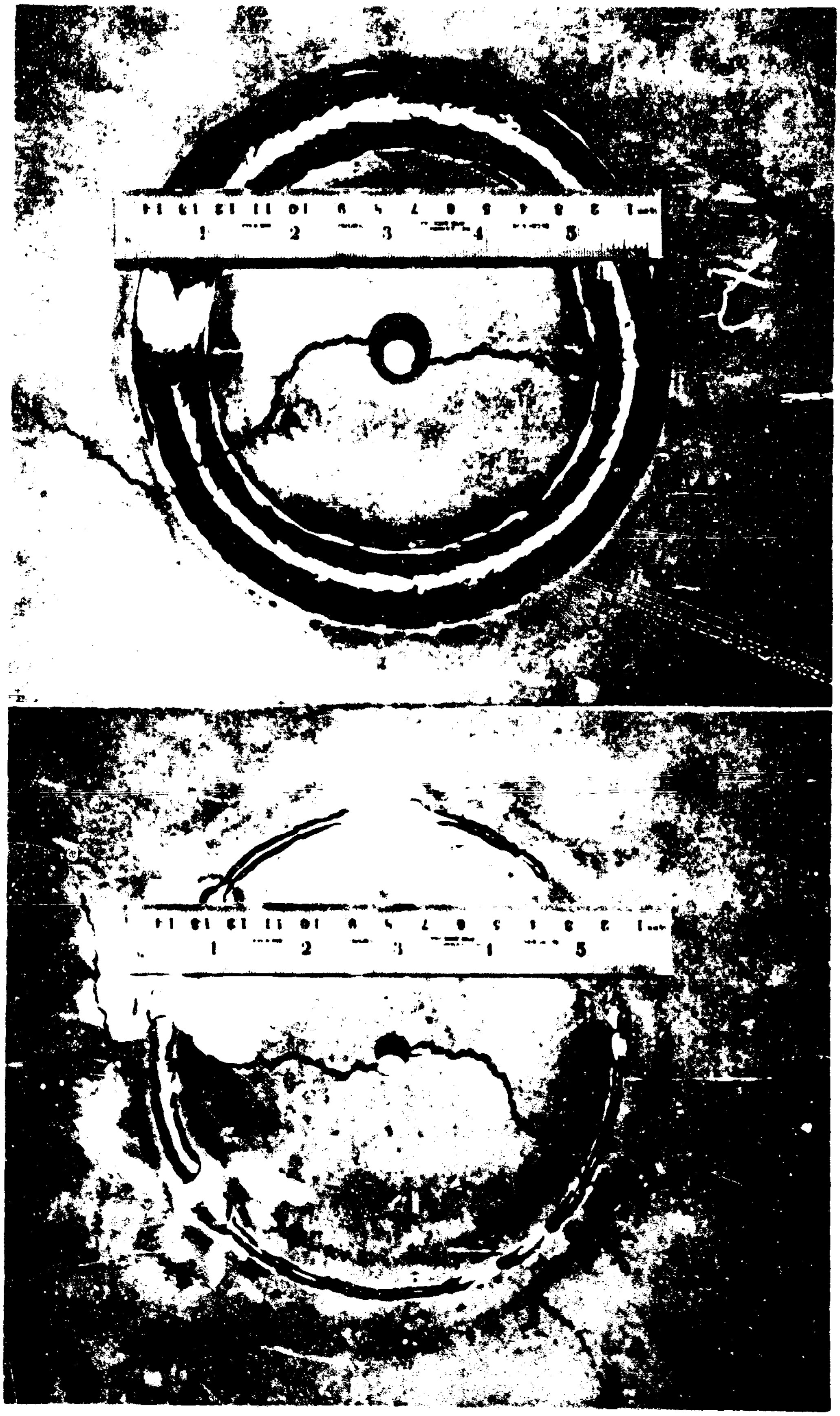


FIGURE 4.13 Ti-7Al-2Cb-1Ta 1/2 inch thick, 5 inch diameter circular patch restrained weld specimen. Stress corrosion cracking occurred after 153 days in 80' lot at Inco Harbor Island (Kure Beach) Corrosion Laboratory.

Figure 4.14 Unwelded and welded [illegible] Static Corrosion Specimens after sixth monthly removal. Left weld - heat treated, right weld - exposed as welded.

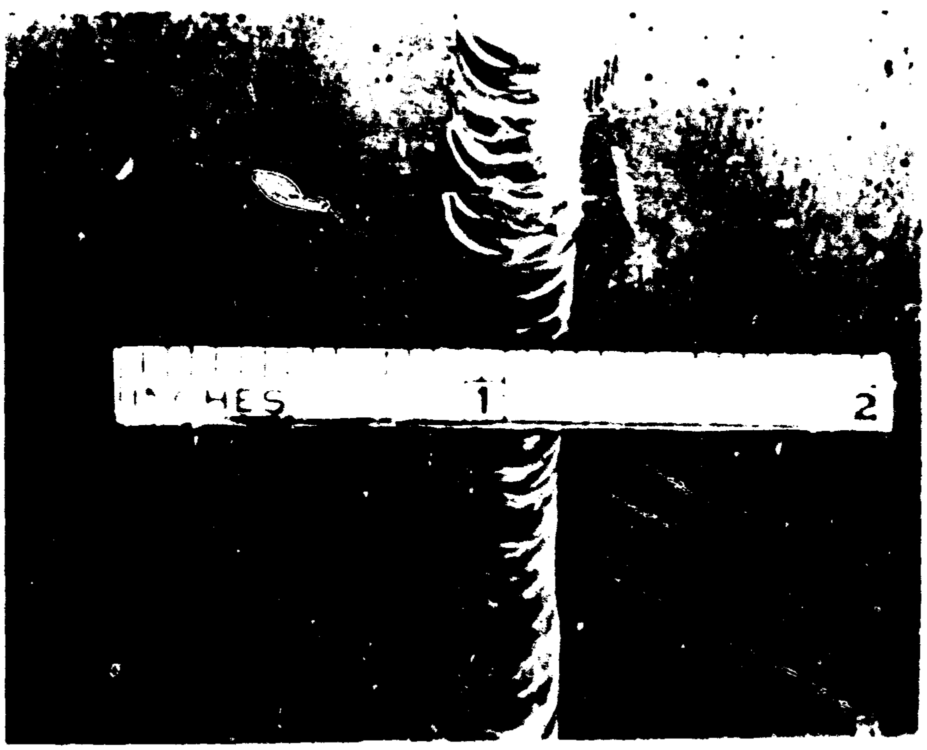


Figure 4.15 Close-up of cracked area in right weld of Specimen shown in Figure 4.14 (Above Figure)

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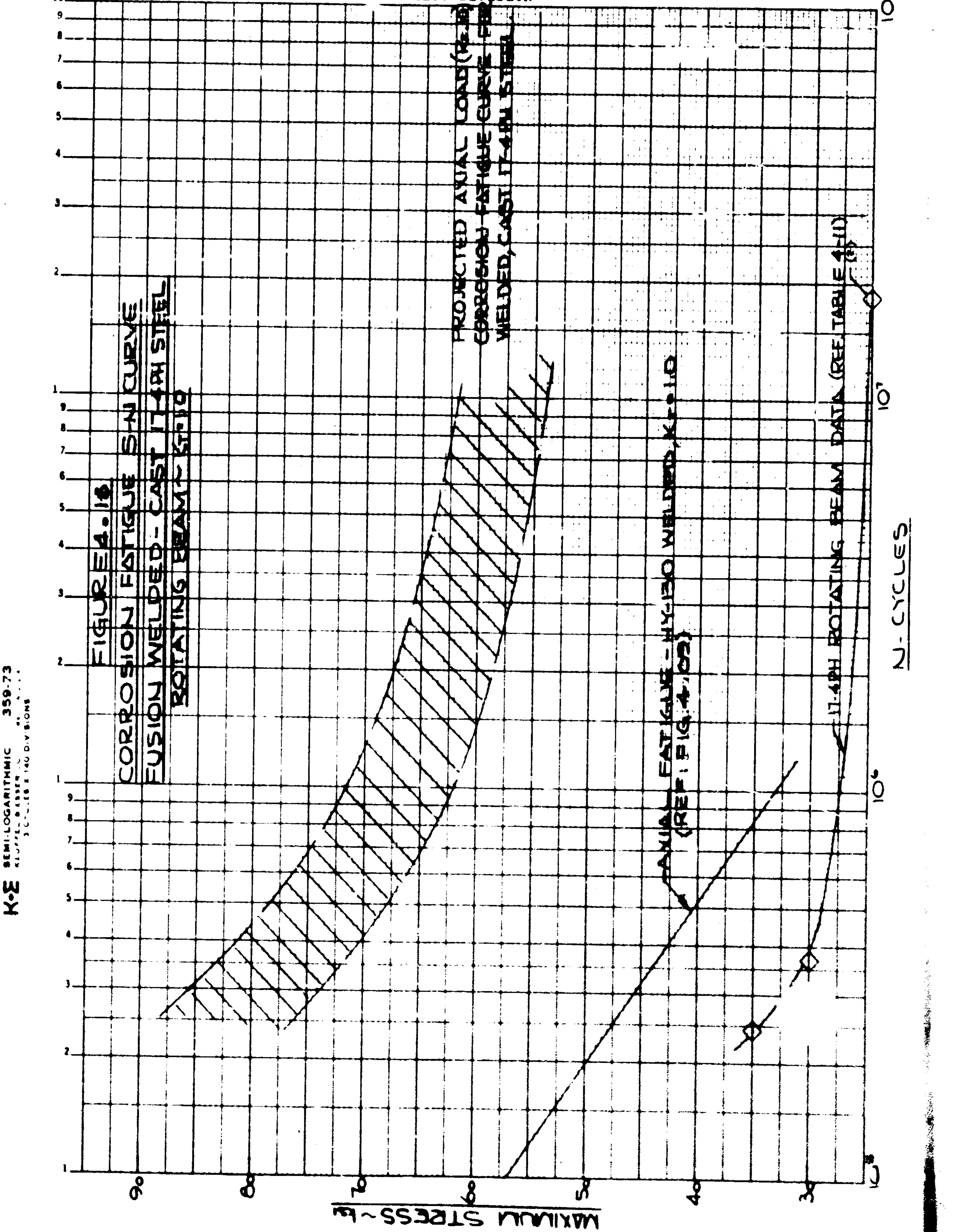


FIGURE 4.18
CORROSION FATIGUE S-N CURVE
FUSION WELDED-CAST 17-4PH STEEL
ROTATING BEAM Kt=1.0

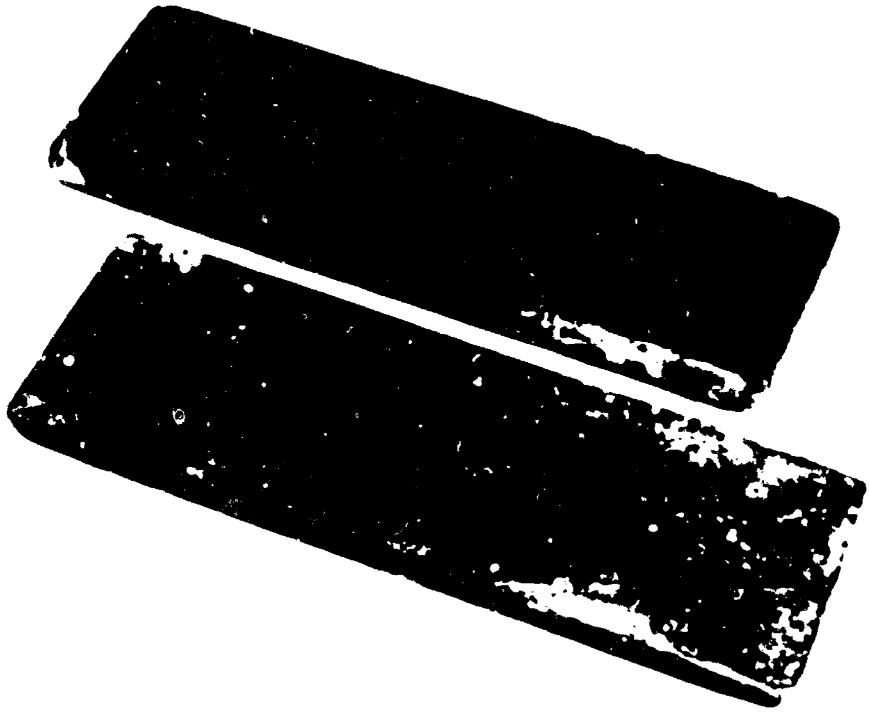


Figure 4.17 [illegible]
9 months [illegible]

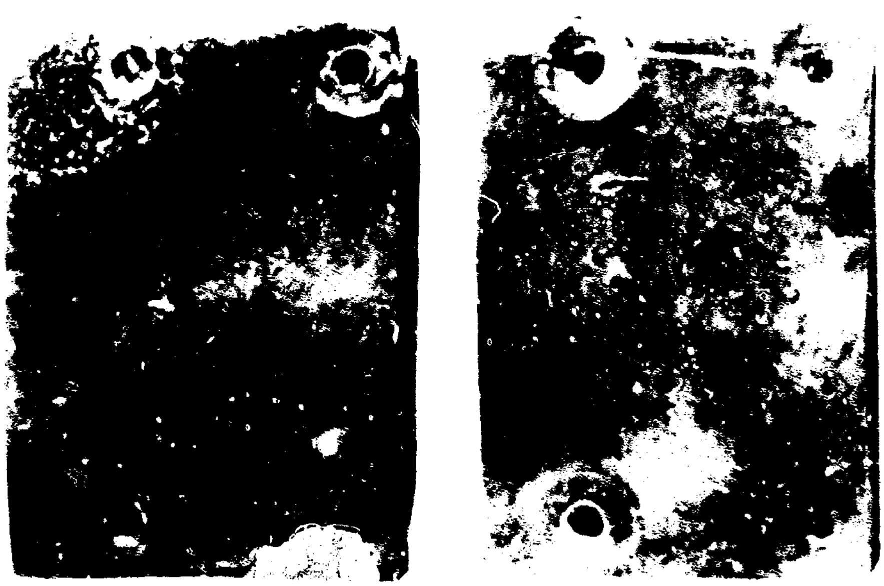
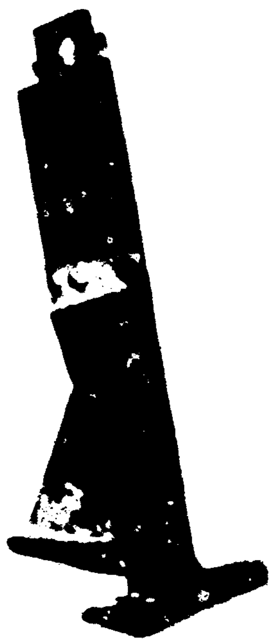


Figure 4.18 [illegible]

Figure 419 20 mils Goodyear 23-56 Neoprene over 3 mils flame sprayed 1100aluminum (Top) and Andrew-Brown Co. M-1500 Zinc Rich Epoxy - Polyamide Primer (Bottom) on HY130 after 27 hours exposure to 90 knot Sea Water Impingement at 45° angle.



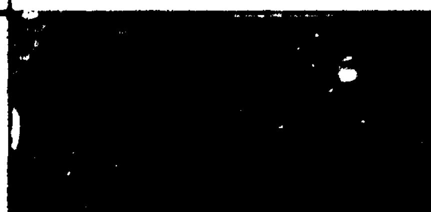
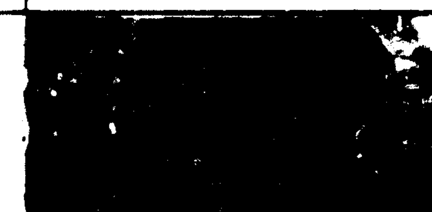
VELOCITY (FPS)	[illegible]		[illegible]		150
SPECIMEN AFTER TEST					
COATING THICKNESS (MILS)	[illegible]		25		18
CONDITION AFTER TEST	No apparent damage		Scuffing		Perforated
SPECIMEN AFTER TEST					
COATING THICKNESS (MILS)	35		26		35
CONDITION AFTER TEST	No apparent damage		Scuffing		Eroded, not Perforated

Figure 4.21 Naval Applied Science Laboratory Rotating Disc Cavitation - Erosion results for Mosites 60125 Calendered Neoprene Sheet applied over 3 mil flame sprayed 1100 aluminum on SAE 1020 steel disc. See Page 4.23 for Coating Application Procedure and Table 4-15 for Mechanical Properties. Coating thicknesses as indicated. Test Liquid: Fresh water. Flow Rate: 11.9 GPM. Inlet Temperature: 75°F. Outlet Temperature: 83°F. Pressure: 15 PSIG. Test Time: 14 hours. Shaft Speed: 3200 RPM.

5.0 FABRICABILITY DATA AND DISCUSSION

5.1 MACHINABILITY

Comparative machining tests were conducted for Ti 7Al-2Cb-1Ta titanium and HY-130 steel. These materials had the following mechanical properties:

	HY-130 Steel	Ti 7Al-2Cb-1Ta Titanium
Tensile strength, psi	154,500	116,000
0.2% yield strength, psi	141,900	101,000
Elongation (2") %	8	11.5

Machining tests were conducted for the drilling, peripheral end milling, end mill slotting and face milling of these materials. The procedure used and the results obtained for each of these machining operations will be discussed separately in this section.

5.1.1 DRILLING

Both Hy-130 steel and Ti 7Al-2Cb-1Ta titanium are moderately difficult to drill. While no unusual difficulties were encountered in this evaluation, cutting speeds must be kept low in order to drill these materials successfully. These materials have the same machining index when drilled at a cutting speed of 45 surface feet per minute.

Standard, NAS 907, type "B" high speed steel drills, 5/16-inch in diameter were used in these tests. Drill specimens were prepared from 1/2 inch thick plate, and tests were conducted on a positive feed drill press. Drill life was determined for several cutting speeds while holding feedrates constant at 0.006-inch/revolution. Drill life was considered ended when the flanks or corners of the drills had worn 0.015-inch.

Cutting Tool Material - Ordinary M-2, high speed steel proved adequate for drilling these materials; therefore, better materials were not evaluated.

Cutting Tool Geometry - Drill point geometry tests were conducted for HY-130 steel, and the results are shown in figure 5.01. Although the 108° point angle drills were superior to all other point angles investigated, the gains over the 118° point angle drill (which is a standard "off the shelf" drill) were not sufficiently high to justify its use. Consequently the 118° point angle drill was selected for use in further studies. Since previous drill geometry tests conducted on titanium alloys other than the Ti-7Al-2Cb-1Ta yielded results which were nearly indentical to those observed for the HY-130 steel, the 118° point angle drill was also selected for further work with Ti-7Al-2Cb-1Ta. In addition, all drills were ground with split points as shown in figure 5.02

Feeds and Depth of Cut - Due to the nature of this investigation, feed rate and depth of cut were not varied. A feed rate of 0.006-inch per revolution was held constant, and all holes drilled were 0.5-inch through holes.

Cutting Fluids - A heavy sulphur-base cutting oil was used for these tests and good results were achieved.

Cutting Speeds and Tool Life - Taylor tool life curves were plotted for HY-130 steel and Ti 7Al-2Cb-1Ta titanium as shown in figure 5.03 Data were obtained for these curves by varying the speed of each drill and noting drill life while holding all other variables constant. The cutting speed which will produce a desired drill life can be predicted from this graph.

During this study, it was found that stubby, sharp drills and rigid set-ups were very beneficial when drilling both HY-130 steel and Ti 7Al-2Cb-1Ta titanium. Other recommendations for drilling these materials are the same for both alloys and are given as follows:

Cutting Speed:	30 to 40 surface feet/minute
Feed:	0.006-inch/revolution
Cutting Fluid:	Heavy sulphur-base oil
Drill Material:	M-2 high speed steel
Drill Geometry:	118° split point, NAS 907, Type "B"

5.1.2 PERIPHERAL END MILLING

When peripheral (side cutting) end milling, it is easier to machine Ti 7Al-2Cb-1Ta titanium than HY-130. The Ti 7Al-2Cb-1Ta titanium was also found to be easier to machine than other titanium alloys previously machined at LTV. When compared with HY-130 steel, Ti 7Al-2Cb-1Ta titanium has a peripheral end milling machinability index of 187%.

Standard, HSS (high-speed steel), 4-flute end mills, 1/2 and 3/4-inch in diameter were used. One-inch Ti 7Al-2Cb-1Ta titanium and HY-130 plateswere used for test evaluation. Cutting speeds were varied for each test, while a feed rate of 0.0022-inch/tooth and a depth of cut of 0.100-inch were held constant. Tool life was considered ended when the flanks of the cutters had worn 0.010 inch, as the primary clearance surface or margin on the cutters was only 0.012-inch wide. Wearland values were measured with a Bausch and Lomb microscope and tool life was measured by means of a stop watch. Cutting fluid composed of Gulf 45B and 11D, mixed 1:1, was used throughout the test program.

Testing parameters are given below:

Cutting Tool Material - Ordinary high speed steel (probably M-2 or equivalent) proved to be satisfactory for cutting Ti 7Al-2Cb-1Ta titanium and HY-130 steel; therefore, better materials were not evaluated.

Cutting Tool Geometry - This factor was not investigated; however, standard end mills having a 30° helix angle and 10° radial rake angle were pre-selected for this study. Such a tool geometry has a 21°18' effective rake angle, whereas a 45° helix angle and 10° radial rake angle tool has a 34°11' effective rake angle. Based upon the best information available, the latter tool geometry would be too "high shear" in this case.

Feeds and Depths of Cut - Due to the nature of this investigation, these parameters were not varied. A feed rate of 0.002 inch/tooth and 0.100 inch depth of cut were held constant. Based on past experience, heavier cuts can be made in titanium than steel.

Cutting Fluids - Titanium has a low thermal conductivity; therefore, a good coolant and anti-weld cutting fluid is needed when machining this material. A cutting fluid consisting of one part Gulf 45B (heavy sulfur base oil) and one part Gulf 11D (mineral-lard oil) was used in this study, and creditable results were achieved for both Ti 7Al-2Cb-1Ta titanium and HY-130 steel.

Tool Life - A tool life curve was plotted for Ti 7Al-2Cb-1Ta titanium and HY-130 steel as shown in figure 5.04 . Data for this curve were obtained by varying cutting speed for each tool and noting tool life while holding all other variables constant. The cutting speed required to yield a desired tool life can be predicted from this graph.

Most Economical Cutting Speed - The cutting speed which will yield the greatest economies can be calculated from the following equation and figure 5.04:

$$T = \left(\frac{1}{n} - 1\right) \left(\frac{t}{M} + TCT\right)$$

T = Most economical tool life.
n = Slope of "cutting speed versus tool life" curve.
t = Total cost of cutter; includes costs of regrinding cutting edges, tool depreciation and tool changing.
M = Machine, labor, and overhead rate ($/min.)
TCT = Tool changing time (minutes).

While actual costs have not been determined for the above parameters, a reasonable estimate can be made. Standard, 3/4-inch diameter, 4-flute, end mills cost $4.05. Assuming that each tool can be reconditioned six times at 20 minutes per tool, "t" will be equal to $1.44. Upon measuring the slope of the curve shown in figure 5.04 , "n" is found to be equal to 0.17. Based on a previous study, "M" was found to be $0.17, and "TCT" is estimated to be 5 minutes. Upon substituting these data into the above equation, the most economical tool life for Ti 7Al-2Cb-1Ta titanium is found to be 66 minutes. From figure 5.04 , the cutting speed which will yield such a tool life is found to be 117 surface feet per minute, and this is the estimated "most economical cutting speed."

The most economical tool life for HY-130 steel is found to be 20 minutes, and from figure 5.04, the cutting speed which will yield such a tool life is found to be 100 surface feet per minute, which is the estimated "most economical cutting speed."

Recommendations for peripheral end milling of Ti 7Al-2Cb-1Ta titanium and HY-130 steel are given below:

	Ti 7Al-2Cb-1Ta Titanium	HY-130 Steel
Cutting Tool	Putman hi-speed, 4-flute end mill or equivalent	
Tool Geometry		
Helix	30°	30°
Radial Rake	10°	5°
Clearance	10°	5°
Cutting Speed (feet/minutes)	116	110
Feed (inch/tooth)	0.0022	0.0022
Depth of Cut (inch)	0.100	0.100

5.1.3 END MILL SLOTTING

HY-130 steel is easier to slot with end mills than Ti 7Al-2Cb-1Ta titanium. For this type of milling, the Ti 7Al-2Cb-1Ta titanium machines somewhat like steel heat treated to 180,000 psi. When compared with HY-130 steel, Ti 7Al-2Cb-1Ta titanium has an end mill slotting machinability index of 88%.

Machining cuts 0.250 inch deep by 18 inches long were made progressively with 3/4-inch diameter end mills in an edge of a one-inch thick plate held vertically in a table vice. When a depth of 1-3/4 inches was achieved, the end mills bottomed out, thus the slots were machined away so that tests could be continued. Standard, hi-speed steel 4-flute end mills were used. Cutting speeds were varied for each test while a feed rate of 0.0022 inch/tooth and a depth of cut of 0.250 were held constant. In addition, a copious flow of cutting fluid was used throughout the test program. Tool life was considered ended when the flanks of the cutters had worn 0.010 inch. Wearland values were measured with a Bausch and Lomb microscope, and tool life was measured by means of a stop watch.

Testing parameters are given below:

Cutting Tool Material - Ordinary high speed steel (probably M-2 or equivalent) proved to be adequate for cutting Ti 7Al-2Cb-1Ta titanium and HY-130 steel in these tests; therefore, better materials were not evaluated.

Cutting Tool Geometry - This factor was not evaluated. The same tool geometry used for the peripheral end milling tests with these materials was used in this study. This geometry consists of a 30 degree helix angle, 10 degree radial rake angle, and 10 degree clearance angle for milling Ti 7Al-2Cb-1Ta titanium, and a 7 degree clearance angle for milling HY-130 steel.

Feeds and Depths of Cut - Due to the nature of this investigation, these parameters were not varied. A feed rate of 0.0022-inch per tooth and 0.250-inch depth of cut were held constant.

Cutting Fluids - Titanium has a low thermal conductivity; therefore, a good coolant and anti-weld cutting fluid is needed when machining this material. A cutting fluid consisting of one part Gulf 45B (heavy sulfur base oil) and one part Gulf 11D (mineral-lard oil) was used in this study, and creditable results were achieved for both Ti 7Al-2Cb-1Ta titanium and HY-130 steel.

Tool Life and Cutting Speed - A tool life curve was plotted for Ti-7Al-2Cb-1Ta titanium and HY-130 steel as shown in figure 5.05 . Data for this curve were obtained by varying the cutting speed for each tool and noting tool life while holding all other variables constant. The cutting speed required to yield a desired tool life can be predicted from this graph.

Most Economical Cutting Speed - The cutting speed which will yield the greatest economies can be predicted from figure 5.05 and the following equation:

$$T = \left(\frac{1}{n} - 1\right)\left(\frac{t}{M} + TCT\right)$$

where T = Most economical tool life
n = Slope of "cutting speed-tool life" curve
t = Total cost of cutter; includes cost of regrinding cutting edges, tool depreciation and tool changing
M = Machine, labor, and overhead rate ($/minute)
TCT = Tool changing time

Upon substituting calculated and measured data into the above equation, the most economical tool life is found to be 99 minutes for end mill slotting of Ti 7Al-2Cb-1Ta titanium. From figure 5.05, the cutting speed which will yield such a tool life is not clearly evident. As can be seen, the slope of the tool life curve changes at some point beyond a tool life of 60 minutes or a cutting speed of 64 feet/minute. As a result, a reduction in cutting speed below 64 feet/minute may not increase tool life significantly. Such a possibility would be characteristic of titanium; and for these reasons, a most economical cutting speed may not be determinable by this method for the end mill slotting of Ti 7Al-2Cb-1Ta titanium. Upon extrapolating the basic curve shown in figure 5.05, it can be observed that a cutting speed of 58 feet/minute might yield a tool life of 99 minutes. In either event, a cutting speed of 58 feet/minute will yield a good tool life and is considered the "most economical cutting speed."

For end mill slotting of HY-130, the most economical tool life is found to be 35 minutes. From figure 5.05, the cutting speed which will yield such a tool life is observed to be 84 feet/minute, and is the estimated "most economical cutting speed."

Recommendations for end mill slotting of Ti 7Al-2Cb-1Ta titanium and HY-130 steel are given below:

	Ti 7Al-2Cb-1Ta Titanium	HY-130 Steel
Cutting Tool	Putman, hi-speed steel, 4-flute, end mill or equivalent.	
Tool Geometry		
Helix	30°	30°
Radial Rake	10°	10°
Clearance	10°	7°
Cutting Speed (feet/minutes)	58	84
Feed (inch/tooth)	0.0022	0.0022
Depth of Cut	0.250	0.250

5.1.4 FACE MILLING

HY-130 steel was found to be extremely easy to face mill, but Ti 7Al-2Cb-1Ta titanium was not. When compared with HY-130 steel, Ti 7Al-2Cb-1Ta titanium has a face milling machinability index of 29%. However, Ti 7Al-2Cb-1Ta titanium is as easy, if not easier, to face mill than many other titanium alloys. Evidently, carbide cutting tools are not as beneficial when cutting titanium as they are when cutting steel. For this reason it would probably be best to slab mill Ti 7Al-2Cb-1Ta titanium with high speed steel cutters whenever possible.

Single-tooth fly-cutters were used during this evaluation. The tool inserts used in the fly-cutters were prepared with brazed carbide tips. C-2 (883) carbide was used to face mill Ti 7Al-2Cb-1Ta titanium and C-6 (370) carbide was used for HY-130 steel. Workpiece specimens were prepared from one-inch thick plate and were held by clamping them to the milling machine table.

Cutting speeds were varied for each test while a feed rate of 0.0075-inch per tooth and a 0.100-inch depth of cut were held constant. Tool life was considered ended when flanks of cutters had worn 0.015-inch. Wear-land values were measured with a Bausch and Lomb microscope, and tool life was measured by means of a stop watch.

Testing parameters are given below:

Cutting Tool Material - It had been found previously that C-2 was the best general grade of carbide for machining titanium and C-6 for machining HY-130; therefore, no additional tests were conducted on cutting tool materials.

Cutting Tool Geometry - Initially, tests were conducted with the commercial (Lovejoy) tool geometry that was predicted best for titanium. This cutter had an axial rake of 7^{o} and a radial rake of 3^{o}. When a 45^{o} corner angle was ground on these tools, the functional angles consisted of an inclination angle of 2.85^{o} and an effective rake angle of 7.2^{o}. In ensuing tests, these cutters performed poorly; and fault was placed on the positive inclination angle which these tools possessed. It was found that a corner angle of at least 75^{o} would have to be ground on these cutters before a negative inclination angle could be obtained. This being impractical, another tool geometry was sought. The tool geometry selected consisted of a 0^{o} axial rake angle, 7^{o} radial rake angle, and a 45^{o} corner angle. This geometry yielded functional angles of -4.97^{o} (negative) for the inclination angle and 5.37^{o} (positive) for the effective rake angle. Such a tool geometry was considered ideal for machining titanium and was used in this study.

A different tool geometry was used to face mill HY-130 steel. These tests were conducted with the commercial (Lovejoy) tool geometry which is ordinarily used for face milling steel. This geometry consists of a -6^{o} axial rake angle and -10^{o} radial rake angle. When a 45^{o} corner angle was ground on tools having this geometry, functional angles of 2.9^{o} and -11.1^{o} respectively were produced for the inclination and effective rake angle. While such a geometry is not considered ideal for machining the HY-130 material used in this study, excellent results were obtained with this geometry. For this reason, other tool geometries were not investigated, and the above tool geometry was used in this study.

Feeds and Depths of Cut - Due to the nature of this investigation, these parameters were not varied. A feed rate of 0.0075-inch/tooth and 0.100-inch depth of cut were held constant.

Cutting Fluids - Titanium has a low thermal conductivity; therefore, a good coolant and antiweld cutting fluid is needed when machining this material. A cutting fluid consisting of one part Gulf 45B (heavy sulfur base oil) and one part Gulf 11D (mineral-lard oil) was used and creditable results were achieved. Cutting fluids were not found necessary when face milling HY-130 steel with carbides; therefore, no cutting fluids were used.

Tool Life and Cutting Speed - A tool life curve was plotted for Ti 7Al-2Cb-1Ta titanium and HY-130 steel as shown in figure 5.06. Data for these curves were obtained by varying the cutting speed for each tool and noting tool life while holding all other variables constant. The cutting speed required to yield a desired tool life can be predicted from this graph.

Most Economical Cutting Speed - The cutting speed which will yield the greatest economies can be predicted from figure 5.06 and the following equation:

$$T = \left(\frac{1}{n} - 1\right) \left(\frac{t}{M} + TCT\right)$$

where T = Most economical tool life
n = Slope of "cutting speed - tool life" curve
t = Total cost of cutter; includes costs of regrinding cutting edge, tool depreciation, and tool changing
M = Machine, labor, and overhead rate ($/minute)
TCT = Tool Changing Time

While actual costs have not been determined for the above parameters, a reasonable estimate can be made. A 4-inch diameter, inserted, 5-tooth, face mill, cutter body costs $180. Assuming that this body can be used 100 times and each carbide cutting edge costs $0.50; then "t" will equal $4.30. Upon measuring the slope of the curve shown in figure 5.06, "n" is found to equal 0.32 for Ti 7Al-2Cb-1Ta titanium and 0.25 for HY-130 steel. Based on a previous study, "M" was found to be $0.17; and "TCT" is estimated to be 10 minutes. Upon substituting these data into the above equation, the most economical tool life is 75 minutes for Ti 7Al-2Cb-1Ta titanium and 106 minutes for HY-130 steel. From figure 5.06, the cutting speeds which will yield such a tool life are observed to be 155 surface feet per minute for Ti 7Al-2Cb-1Ta titanium and 480 surface feet per minute for HY-130 steel and are the estimated "most economical cutting speeds."

Recommendations for face milling of Ti 7Al-2Cb-1Ta titanium and HY-130 steel are given below:

	Ti 7Al-2Cb-1Ta Titanium	HY-130 Steel
Cutting Tool	Insert or Disposable Blade, Carbide, Face Mill	
Tool Geometry		
Axial Rake	0°	-6°
Radial Rake	7°	-10°
Corner Angle	45°	45°
Clearance Angle	10°	6°
Nose Radius (inch)	1/32	1/32
Tool Material	C-2 Carbide	C-6 Carbide
Cutting Speed (feet/minute)	155	480
Feed (inch/tooth)	0.0075	0.0075
Depth of Cut (inch)	0.100	0.100
Cutting Fluid	Gulf 45B and 11D (1:1)	none

Tool Material: HSS
Tool Geometry: 5/16" Diameter, 2 Flute, Crankshaft Point (CVA Split Point) 7° Clearance
Cutting Speed: 83 SFPM
Feed: 0.006 IPR
Depth of Hole: 0.500" through Hole
Coolant: Highly Sulphurized Oil
Wear Land: 0.015

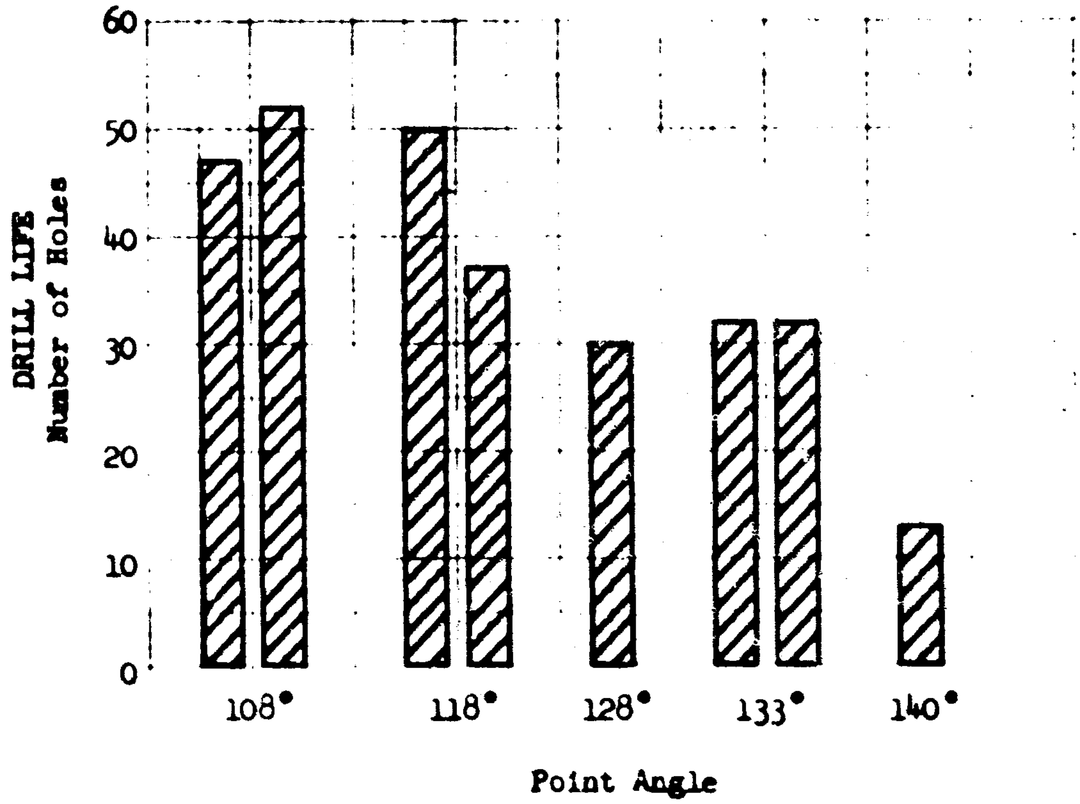
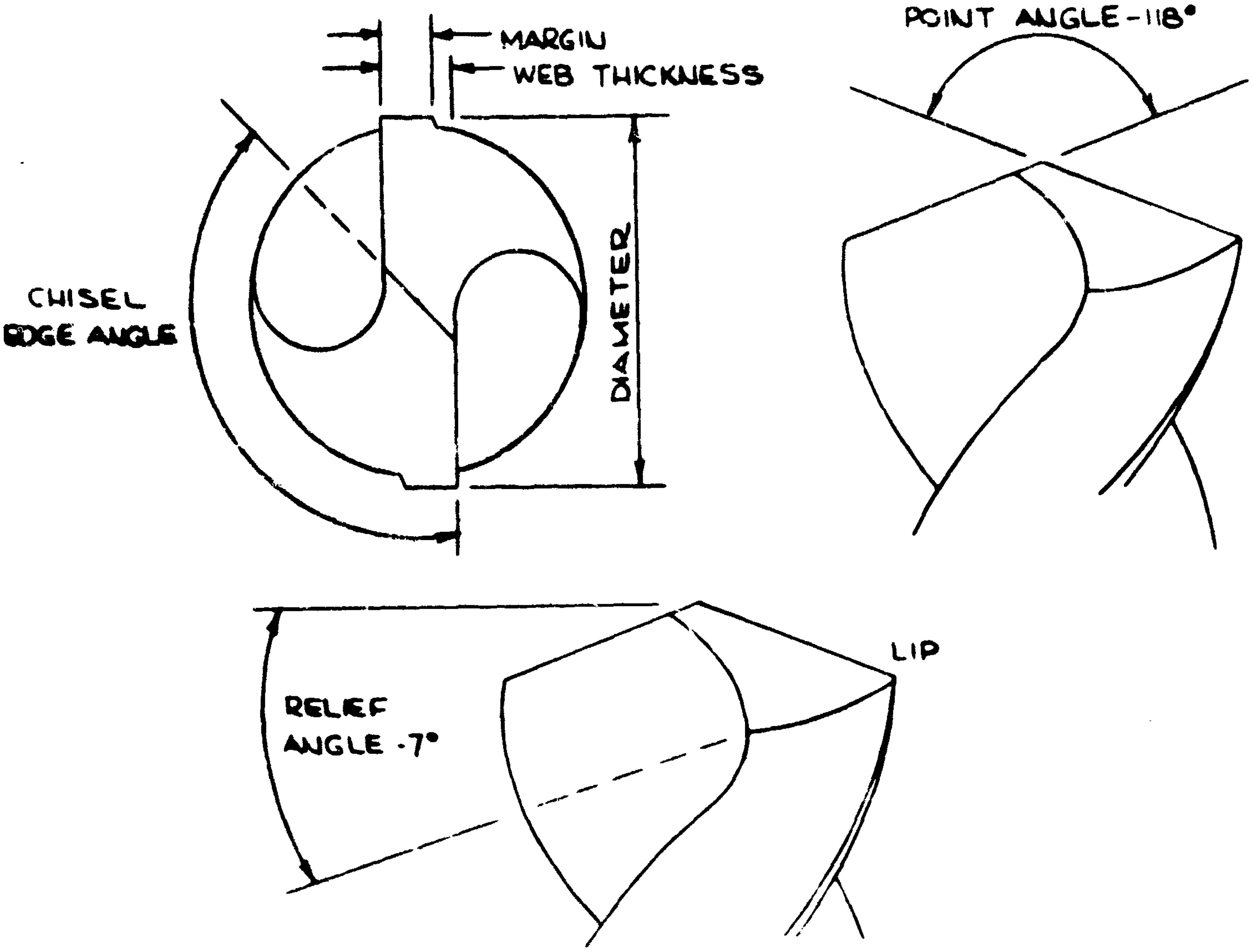


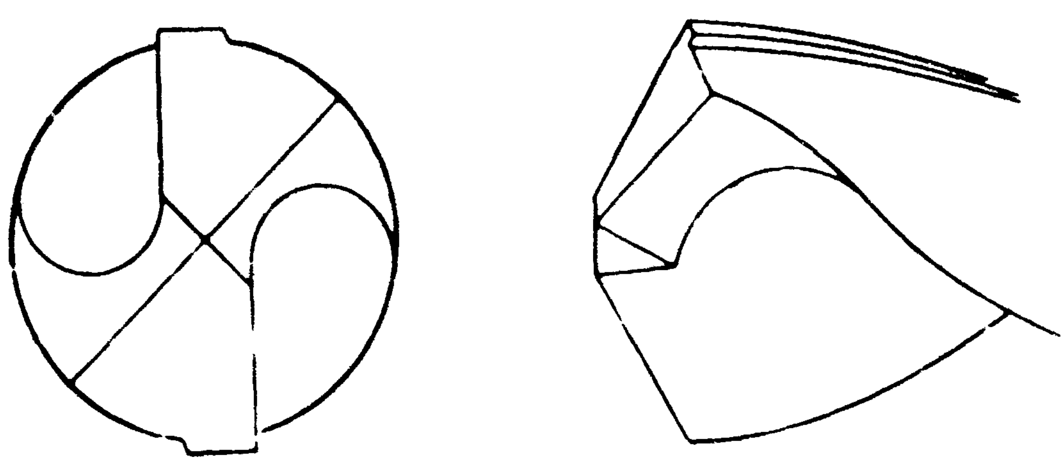
Fig 5.01 EFFECT OF DRILL GEOMETRY ON DRILLING HY-130

FIGURE 5.02

DRILL POINT GEOMETRY



STANDARD POINT GRIND



SPLIT POINT GRIND

LTV VOUGHT AERONAUTICS DIVISION

Cutting Speed: As shown
Feed: 0.006-Inch per revolution
Depth: 0.5-Inch thru holes
Cutting Fluid: Gulf 45B and 11D (1:1)
Cutting Tool: NAS907, Type "B", HSS, 5/16-Inch Diameter Drills
Wearland: 0.015-Inch

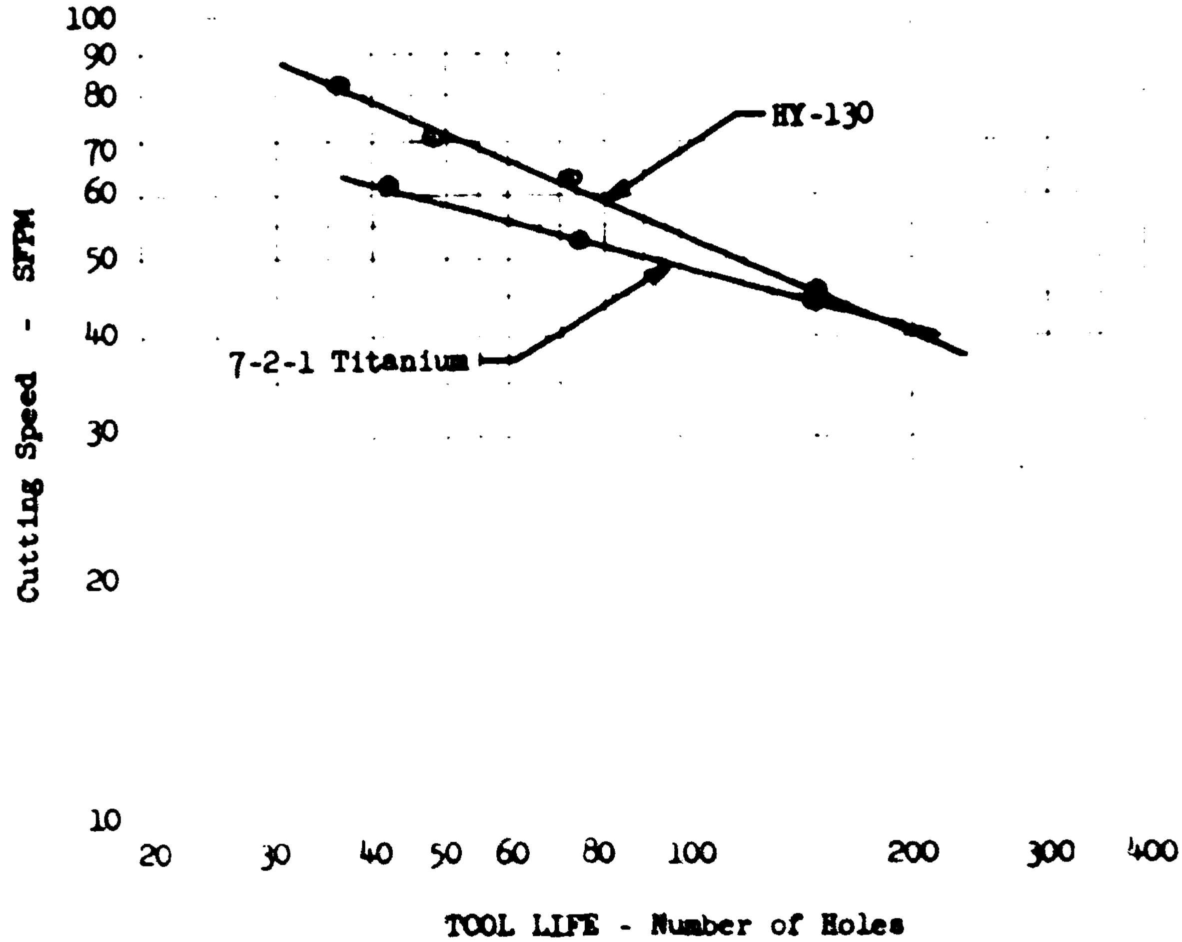


Fig 5.03 EFFECT OF CUTTING SPEED ON DRILLING 7-2-1 TITANIUM AND HY-130

Cutting Speed: As shown
Feed: 0.0022-Inch per tooth
Depth of Cut: 0.100-inch
Cutting Tool: Putnam, 4 Flute, 3/4-inch Diameter, HSS, End Mill
Cutting Fluid: Gulf 45B and 11D (1:1)
Wearland: 0.010-inch

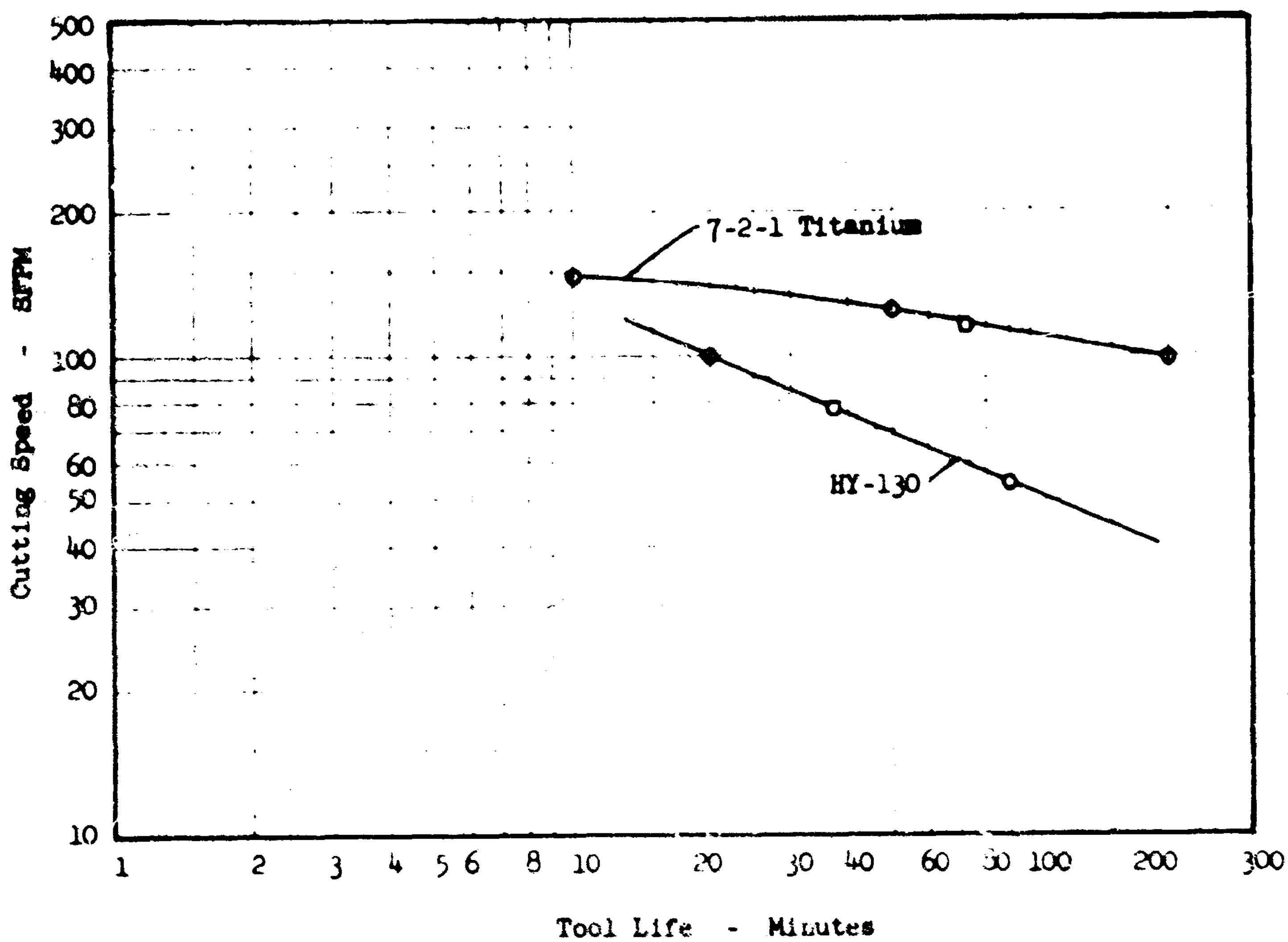
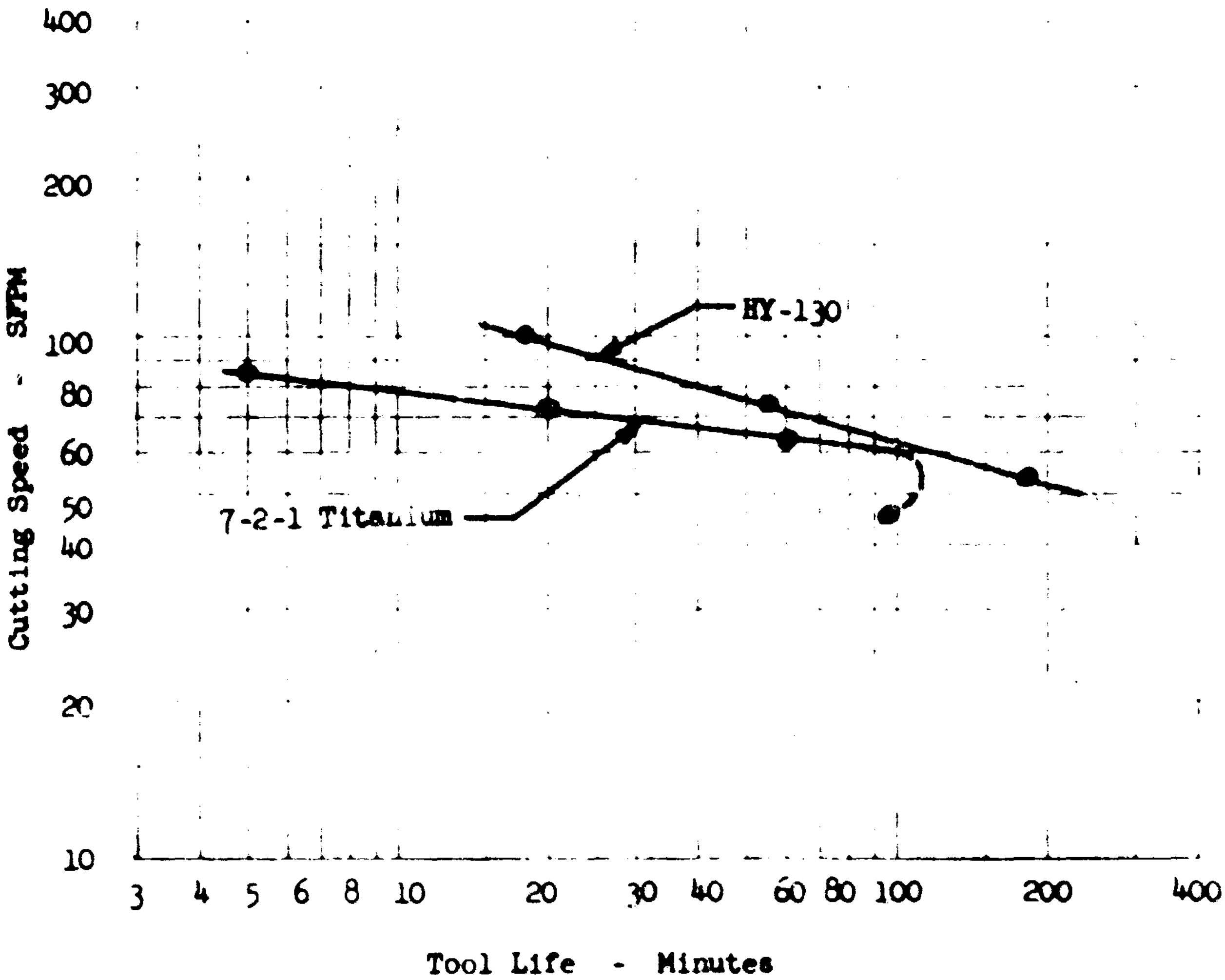


Fig 5.04 EFFECT OF CUTTING SPEED ON TOOL LIFE WHEN PERIPHERAL END MILLING 7-2-1 TITANIUM AND HY-130

Cutting Speed: As shown
Feed: 0.0022-Inch per tooth
Depth of Cut: 0.250-inch
Cutting Tool: Putnam, HSS, 4 Flute, 3/4-inch Diameter, End Mill
Cutting Fluid: Gulf 45B and 11D (1:1)
Wearland: 0.010-inch



EFFECT OF CUTTING SPEED ON TOOL LIFE
Fig 5.05 WHEN END MILL SLOTTING 7-2-1 TITANIUM AND HY-130

Cutting Speed: As shown
Feed: 0.0075-Inch per tooth
Depth of Cut: 0.100-inch
Tool Material: Titanium - C-2 Carbide
Steel - C-6 Carbide
Cutting Fluid: Titanium: Gulf 45B and 11D (1:1)
Steel: Dry
Wearland: 0.015-inch

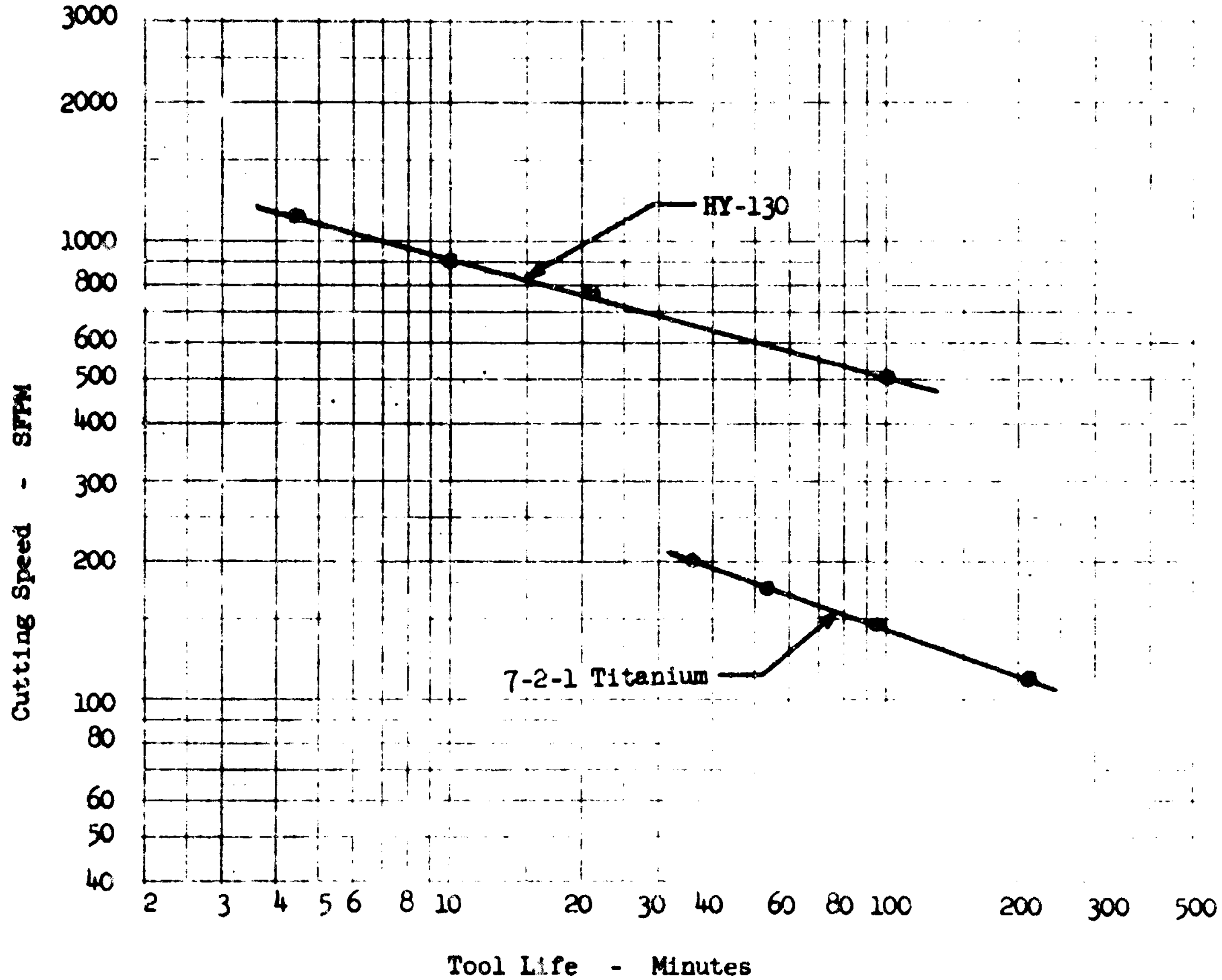


Fig 5.06 EFFECT OF CUTTING SPEED ON TOOL LIFE WHEN FACE MILLING 7-2-1 TITANIUM AND HY-130

5.2 FORMING

The U. S. Naval Applied Science Laboratory, Naval Base, Brooklyn, New York, has performed work in roll bending one-inch thick Ti 7Al-2Cb-1Ta titanium plate. The objective of the program in which this work was done was to develop production forming procedures for heavy section alloy titanium plates and shapes for use in hull structures of advanced deep diving submersibles. (Ref. SF 013-01-03, Task 0216)

The results of these tests of the roll-bending characteristics of Ti 7Al-2Cb-1Ta titanium plate indicate that over a range of extreme fiber strains from approximately 1/2 to 1-2/3 percent and for a yield strength level of 106,000 psi for Ti 7Al-2Cb-1Ta titanium and 90,000 psi for HY-80 steel, which was used for comparison, the following applies:

a. The ratio of energy required to cold roll bend alloy titanium plate compared to that required to cold roll bend HY-80 steel plate varies considerably depending on the strain level; a ratio of 1-1/2 at high strain levels and 4-1/2 at low strain levels were found in these tests.

b. Moderately elevating the roll bending temperature rapidly reduces the energy required to roll bend Ti 7Al-2Cb-1Ta titanium.

c. At 600°F, the energy to roll bend the Ti 7Al-2Cb-1Ta titanium is half that required at room temperature and for strain levels above 1% is no greater than the energy required to roll bend HY-80 steel at room temperature. Temperatures above 600°F showed little additional reduction in the energy required to roll behd titanium.

d. The springback of the titanium plate used in these tests after cold roll bending is approximately 2 to 2-3/4 times as great as that for HY-80 steel plate.

e. Springback of roll bent titanium may be significantly reduced by bending at elevated temperature, but there is little advantage in bending at temperatures above 600°F.

f. Forming at elevated temperature did not impair the accuracy with which a particular curvature could be produced.

A review of forming requirements of presently existing BuShips hydrofoil vessels, and the AGEH vessel in production, has revealed no special or unique forming problems requiring research effort above that already completed by the U. S. Naval Applied Science Laboratory, Naval Base, Brooklyn, New York. Presently available forming knowledge is believed adequate for the purposes of this program.

5.3 WELDING

The MIG (metal inert gas) welding process was used generally throughout Phase III due to the economy of this process wherever heavy plate is welded. TIG (tungsten inert gas) welding was used in welding the 1/16-inch thick sheet due to the limitations of MIG welding in the thinner gages, and TIG welding was used wherever manual welding was required. The one exception to the above general rule occurred in the manual welding of the one one-inch thick HY-130 (manual weld) test plate, where manual MIG welding was used. The equipment used for manual welding consisted of a P&H 300 amp, AC-DC arcwelder and a Linde HW-20 torch. The MIG welding equipment consisted of the following items:

1) P&H 500 amp constant voltage power supply.

2) Linde EH-2 wire drive.

3) Linde SCC-6 wire drive control unit.

4) Linde HW-13 torch.

5) Side beam carriage with Linde EG-103 governor.

Tentative checks of yield strength and toughness of the "as welded" properties were made during these welding evaluations of the welds that appeared promising. Where these tests were made the results are included in the welding procedure tables.

MIG welding equipment used in the program is shown in figure 5.07 except for the power supply and the wire drive control unit. Also shown is the welding fixture used to hold all weld specimen plates during welding except the restrained weld specimen plates. The MIG manually welded plate was also welded in this tool, whereas all TIG manually welded plates were welded without the use of a fixture and in an unrestrained condition. The 1/16 inch thick HY-130 sheet was welded in a conventional stake welding tool. Figure 5.08 shows a closeup view of a HY-130 one-inch thick plate in the welding fixture with the torch in position preparatory to making the first root pass weld.

All welding wire was used as received from the vendor, with no surface finish specified. In the case of the titanium filler wire, purchase orders specified that the wire must be packaged to prevent moisture and dirt contamination during shipment. When welding the titanium plates some difficulty was experienced in maintaining a straight weld bead. This was apparently due to the helix angle of the coiled wire, as the angle of exit of the wire from the torch would change and shift the position of the weld bead. This caused difficulty when making the finishing weld passes.

Argon gas was used as the shielding cover and backup gas in making all penetration welds by both the MIG and TIG welding processes for both automatic and manual welding. Torch gas used was 100% argon for all welding except MIG welding of HY-130 and 17-4PH plate where argon plus one to two percent oxygen was used. In welding the titanium, protective gas coverage was required to prevent contamination of the hot weld deposit when it was no longer protected by the torch gas. A water-cooled trailing shield (shown in figure 5.09) and argon gas were used to give this protection and prevent contamination. A round cover shield was used when welding the titanium restrained weld specimens and this shield covered the entire weld. Shielding equipment used proved to be adequate at all times for welding titanium.

For the manually welded MIG one-inch thick HY-130 specimen plate, the torch was removed from its holding in the automatic machine and guided manually to make the weld.

Considerable progress is reported by United States Steel on the development of HY-130/150 covered electrodes for manual welding in their sixth progress report on Bureau of Ships contract No. NObs-88540, SR007-01-01, task 853. Tests already completed have resulted in yield strengths of 140 and 141 ksi and energy absorption of 44 ft.-lb. @ 0°F. and 45 ft.-lb. @ +30°F. The program includes plans for considerably more work in this area.

In preparing the plates for welding, two groove geometries were used as shown in figure 5.10. Groove No. 1 was used on all 1/4-inch thick butt welds, restrained welds, 1-3/8 inch thick 17-4PH and 1-3/8 inch thick CD-4MCu stainless steel castings and all preliminary tensile test specimens of one inch plate. Groove No. 2 was used for welding all final test specimens of HY-130 steel and Ti 7Al-2Cb-1Ta titanium one-inch thick plate. This No. 2 groove configuration is being used for two reasons; one, the 50° "V" groove with a 1/16-inch root gap resulted in porosity and cracking in the root passes when welding HY-130 steel, and two it is anticipated that fabrication welding of hydrofoil skin-rib-spar junctions will require this type or a similar groove configuration. In fabricating final test specimens, the simulated rib (usually a 1/2-inch square piece) is machined off.

In making the root passes, it was difficult to achieve the proper penetration in both the HY-130 steel and Ti 7Al-2Cb-1Ta titanium. This problem will be discussed further under the welding of these alloys. Although a complete resolution of this problem was not possible due to limited time and funds, it is believed that the data developed and the conclusions drawn will provide the basic procedures to develop satisfactory root pass welding. Due to the laboratory nature of the welding work performed, all welding procedures given will probably require some modification to meet the specific needs of production. Tables 5-1, 5-2, and 5-3 may serve for welding HY-130 and Tables 5-14 and 5-15 for welding 7Al-2Cb-1Ta titanium.

5.3.1 WELDING OF HY-130 STEEL

Oxweld 84 filler wire was used for all specimen welding of HY-130 steel in Phase III. As mentioned earlier, the MIG welding process was used on all except the .060-inch thick HY-130 steel sheet, which was TIG welded. In order to insure flatness of the one-inch plate after welding, a shim was placed under the 1/2-inch square simulated rib to compensate for plate warpage during welding. Welding procedures are given in Tables 5-1, 5-2, and 5-3.

Weld tests were conducted on filler wires for welding one-inch thick HY-130 steel plate. The wire trade name, diameter, heat number and carbon content are listed in the table below:

Wire	Dia.	Heat No.	Carbon %
Airco (special)	.062	R9376	.14
Airco 608	.045	86364	.16
Oxweld 83	.045	62613E	.13
Oxweld 83	.045	R3320507	.15
Oxweld 83	.030	X42470	.15
Oxweld 83	.062	R31439	.09
Oxweld 84	.045	R661574	.15

Of these filler wires, the Oxweld 83 (heat no. R3320507) and Oxweld 84 (heat no. R661574) with .15% carbon content were determined acceptable for use in this program. The Union Carbide Corporation, producer of Oxweld 83, has discontinued the marketing of Oxweld 83 with the higher carbon content and is now marketing the higher carbon content wire as Oxweld 84. The Oxweld 83, .030-inch diameter filler wire was not satisfactory due to porosity and lack of fusion in the welds. These weld defects were apparently caused by the inability of the smaller wire to carry the required current satisfactorily. The remaining two Oxweld 83 filler wires, heat no. 62613E and heat no. R31439, did not develop sufficient yield strength for use on this program. The welds made with Airco filler wires were not satisfactory for use on this program. The special .062-inch diameter wire exhibited transverse cracking in the welds and the .045-inch diameter wire resulted in welds of low yield strength. See tables 5-4 through 5-11 for welding procedures and physical properties of HY-130 welded with the above welding wires.

As a result of the low yield strength exhibited by the .045 inch diameter Oxweld 83 wire with .13% carbon, three additional test plates were welded with a lower heat input in order to determine if this would raise the yield strength to an acceptable level. Lowering of the heat input from 27,000 joules per inch to the 15,000 to 19,000 joules per inch level raised the yield strength from 112,000 psi to an average of 130,000 psi. This strength level was not adequate for HY-130 in this program because the desired "as welded" yield strength was 135,000 psi. See table 5-12 for welding procedures and physical properties. Figure 5.11 shows a cross section of a weld in one-inch HY-130 plate.

In making the root passes during the welding of the one-inch thick specimen plates to the 1/2-inch square simulated ribs, difficulty was encountered in obtaining adequate and consistent root penetration. Longitudinal cracking and considerable porosity were experienced in making some of these root passes. Cracking and porosity were not found in all root passes or in all plates, but non-uniform penetration was common to all plates welded. Limited cracking was found on one plate in the area of poor penetration. The porosity was generally found in the first pass where the weld puddle made an apparent cold lap on the simulated rib. This was not always the case, however, because this porosity was not found in all the plates welded.

Upon observing the results of the limited amount of research possible in this program in obtaining good MIG welding root pass parameters for the joint used over the simulated rib, it is believed that it would be better to make these root passes with TIG welding, and then fill the rest of the groove using the MIG process. With copper backup bars and enough time, it is believed that MIG welding root pass parameters could be developed, and thus only one welding process would be required to weld the joint; however, in certain closeout weld joints backup bars cannot be used, and the possibility of using MIG welding in these cases without copper backup bars and obtaining good welds is questionable.

5.3.2 WELDING OF 7Al-2Cb-1Ta TITANIUM

During the early part of Phase III, metal inert gas spray arc and metal inert gas short arc welding of one inch thick Ti 7Al-2Cb-1Ta plates were observed at the Naval Applied Science Laboratory in Brooklyn, New York. The exceptionally good results being obtained were discussed with NASL personnel, who explained at length the welding procedures and shielding and welding equipment being used. The techniques and procedures and the trailer shield configuration used on this program were generally patterned after those used by NASL.

As stated previously, all Ti 7Al-2Cb-1Ta welds were made using a 1/16 inch root gap (groove geometry No. 1) except those made in the one-inch plate for fabrication of final test specimens. The penetration in the 1/16 inch root gap welds was satisfactory in most welds. Attempts to develop root pass weld parameters using .062 inch diameter wire, a 3/8 inch root spacing and a 1/2 inch square simulated rib were unsatisfactory. When the root was penetrated the molten metal flowed through leaving a gap between the plate and the rib, and when the root was not penetrated, the molten metal flowed across the rib to the opposite side without penetrating the root on that side. Due to this, a 1/2" thick by 1" wide simulated rib was used with a single root pass. A cross section of this weld is shown in figure 5.12. This single root pass was acceptable for welding the one-inch plate for fabrication of the final test specimens.

To make a satisfactory penetration root pass weld with .062 inch diameter wire, a 3/8 inch root spacing and a 1/2 inch square simulated rib; either the first two passes should be TIG passes or smaller diameter wire should be used if MIG welding must be used. A large size wire MIG weld could then be used for the remaining passes to complete the weld. Another possibility would be to use copper backup bars, but these could not be used for a close-out weld.

Before welding the final test specimen plates, a preliminary tensile test weld was made in one inch plate in which a weld strength value equal to the parent metal was obtained. One of the two preliminary tensile test specimens made, failed in the parent metal. See table 5-13 for welding procedures and test results.

The 1/2, and 1 inch thick plates were welded satisfactorily, and x-ray inspection revealed no cracking and a relatively small amount of porosity. In welding the one-inch plates, a 1/8 inch thick shim was placed under the simulated rib to compensate for the warping of the plate during welding. A 1/4 and a one-inch plate thickness restrained weld patch test, each with a five-inch diameter patch in a twelve-inch square plate were welded and found free from cracks immediately after welding. These specimens were x-rayed again in nine days and found still free from cracks. See tables 5-14 and 5-15 for welding parameters. Tables 5-16 and 5-17 give recommended settings for welding of 1/4 inch and one-inch Ti 7Al-2Cb-1Ta titanium butt joints.

In the welding of 1/4 inch thich plate, one pass MIG welds were used on butt joints, and a two pass MIG weld was used on the restrained weld pass, using the selected weld parameters, did not quite fill the groove of the patch test specimen, and a second pass was used. It is recommended, however, in MIG welding of 1/4 inch thick plate, that if possible, one pass welds be made.

5.3.3 WELDING OF 17-4PH STAINLESS STEEL CASTINGS

The 1/4 inch thick 17-4PH stainless steel casting stress corrosion specimens, with the 1/8 inch wide by 1/8 inch deep saw cuts simulating repair weld area, were manually TIG welded using 1/16 inch diameter 17-4PH stainless steel filler wire. All weld specimens were found to be free of cracks and porosity upon x-ray inspection except one, and its weld contained a small amount of porosity which was believed caused by improper cleaning before welding.

In welding the 1-3/8 inch thick 17-4PH stainless steel casting by the MIG welding process, a sound weld was not obtained. In welding the first five passes, pure argon was used as the shielding gas with the result that considerable weld spatter occurred, and cracks approximately 1/2 inch long were visible in the weld crater at the end of each weld pass. With the use of 2% O_2 addition to the argon in the sixth and successive passes, the weld spatter and cracking were eliminated. Inspection by x-ray showed a sound weld except for the cracks at the ends of the weld passes as described above. However, when the weld was sectioned, numerous internal cracks were found which were not shown by x-ray inspection. See table 5-18 for welding procedures.

Due to the cracking experienced in the weld when MIG welding was used, the casting was remachined and then TIG manually welded. No restraint was imposed during this TIG welding. A number of weld trials were made with variations of preheat and amounts of filler wire deposited during the first two passes. Excessive warpage and root pass cracking was experienced. Cracking was minimized by making a large proportion of filler wire deposit to base metal melted in the root passes. Due to the excessive warping of the plate, the back side of the plate was machined out after the 10th weld pass and approximately 1/2 inch of the 5/8 inch of weld metal was removed. See figure 5.13 showing warping of this plate. After machining, the plate was straightened and excessive warpage was reduced during rewelding by alternately welding on both sides of the plate. Table 5-19 presents the weld procedures.

5.3.4 WELDING OF CD-4MCu CASTINGS

The 1/4-inch thick CD-4MCu casting static corrosion and stress corrosion specimens, with the 1/8-inch wide by 1/8-inch deep saw cuts simulating repair weld areas, were manually TIG welded using 1/16-inch diameter CD-4MCu filler wire. All specimens were found to be free of cracks and porosity by x-ray inspection except one which had a small amount of porosity which was believed caused by improper cleaning and failure to remove heat treat scale from the specimen before welding.

One 1-3/8-inch thick CD-4MCu plate casting was MIG welded using 1/16-inch diameter CD-4MCu filler wire. Inspection by x-ray revealed no cracks, but did show a small amount of porosity. When the weld was sectioned, however, numerous internal cracks were found. Due to the numerous cracks resulting from automatic MIG welding, it was planned to manually TIG weld this plate. This alloy was dropped from the program for reasons other than welding, however, before the welding could be started. See table 5-20 for welding procedures.

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TABLE 5-1

AUTOMATIC MIG WELDING PROCEDURES

Material:	1" HY-130 Plate
Filler Wire:	.045" diameter Oxweld 84, heat R661574
Shielding Gas (cubic feet/hr)	
Backup:	20 CFH argon
Torch:	50 CFH argon + 1% O_2
Root Spacing:	3/8" - 25° bevel angle - 1/16" land, butt joint

Pass No.	1-2	3-17
Voltage (volts):		
Setting	BC-15	BC-4
Reading	28	30
Current (amperes):		
Setting	98	88
Reading	230	230
Torch Travel (in/min):		
Setting	5.9	4.0
Travel	20	16
Wire Extension (inches):	5/8	5/8
Heat Input (joules/in):	1[illegible],000 **max**	2[illegible],000 **max**
Cabinet Controls:		
Inching	35	35
Range	Low	Low
Burnback	4	4
Slope	2	2
Preheat (°F):	300^{+50}_{-00}	
Max Interpass temp. (°F):	$3[illegible]5^{+50}_{-00}$	230^{+50}_{-00}

Weld Results: These parameters resulted in a good weld except for porosity and limited cracking in the first two penetration passes of some of the welds.

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TABLE 5-2

AUTOMATIC MIG WELDING PROCEDURES

Material:	1/4" HY-130 plate	
Filler Wire:	.045" diameter Oxweld 84, heat R551574	
Shielding Gas (cubic feet/hr):		
Backup:	15 CFH argon	
Torch:	50 CFH argon + 1% O_2	
Root Spacing:	1/16" - 25° bevel angle - 1/16" land, butt joint	
Pass No.	1	2
Voltage (volts):		
Setting	AD-10	BC-7.6
Reading	29	34
Current (amperes):		
Setting	98	38
Reading	270	270
Torch Travel (in/min)		
Setting	7.5	5.0
Travel	27	24
Wire Extension (inches):	5/8	5/8
Heat Input (Joules/in):		
Cabinet Controls:		
Inching	35	35
Range	Low	Low
Burnback	4	4
Slope	2	2
Preheat (°F):	[illegible]	
Max Interpass Temp (°F):		200 $^{+50}_{-00}$

Weld Results: These parameters resulted in a good weld.

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TABLE 5-3

AUTOMATIC TIG WELDING PROCEDURES

Material:	.060" HY-130 sheet
Filler Wire:	.045" diameter Oxweld 84, heat R661574
Shielding Gas (cubic feet/hour):	
Backup:	12 CFH argon
Torch:	50 CFH helium
Joint Type:	Butt joint

Volts:	11
Amperes:	75
Welding Speed:	6" per minute
Electrode extension.	1/2"
Electrode size:	3/32
Electrode point:	3D
Wire feed rate:	20" per minute
Gas Cup diameter:	3/8"
Backup groove width:	.[illegible]5"
Backup groove depth:	.040"
Nose diameter hold down clamp	.200"

These parameters resulted in a satisfactory weld.

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TABLE 5-4

AUTOMATIC MIG WELDING PROCEDURES

Material:	1" HY-130 Plate		
Filler Wire:	.045" diameter Oxweld 83, Heat R3320507		
Shielding Gas (cubic ft/hr)			
Backup	10 CFH, Argon		
Torch	50 CFH, Argon + 1% O_2		
Root Spacing	1/16", butt joint		
Pass No	1	3-4	2 & 5-18
Voltage (volts)			
Setting	AD-2	AD-6.5	AD-8.[illegible]
Reading	22	26	28
Current (amperes)			
Setting	90	92	92
Reading	180	200	220
Torch Travel (in/min)			
Setting	20	15	15
Speed	20	1[illegible]	1[illegible]
Wire Extension (inches)	5/8	5/8	5/8
Heat Input (joules per in)	12,000	19,500	[illegible]
Cabinet Controls			
Inching	35	35	35
Range	Low	Low	Low
Burnback	6	6	6
Slope	2	2	2
Preheat (°F)	200		
Max Interpass Temp (°F)		220	220

Tensile Test (psi)

Specimen No.	Fty	Ftu	e	R.A.	Failure
1	143,200	14[illegible],500	4	13.1	Weld
2	142,000	148,300	5	16.3	Weld

Charpy @ 32°F	65 ft lb
	60 ft lb
	58 ft lb

TABLE 5-5

AUTOMATIC MIG WELDING PROCEDURES

Material:	1" HY-130 Plate	
Filler Wire:	.045" diameter Oxweld 84, Heat R661574	
Shielding Gas (cubic feet/hour)		
Backup:	10 CFH, Argon	
Torch:	50 CFH, Argon + 1% O_2	
Root Spacing:	1/16 inch, butt joint	
Pass No.	1	2-22
Voltage (volts)		
Setting	AD-2	AD-5
Reading	22	25
Current (amperes)		
Setting	90	92
Reading	180	
Torch Travel (in/min)		
Setting	20	16
Speed	20	16
Wire Extension (inches)	3/4	5/8
Heat Input (joules per inch)	12,000	19,500
Cabinet Controls		
Inching	35	35
Range	Low	Low
Burnback	4	4
Slope	2	2
Preheat (°F)	200	
Max Interpass Temp.(°F)		220

Tensile Tests (psi)

Specimen No.	Fty*	Ftu	e	R.A.	Failure
1	140,500	145,700	4		Weld
2	140,300	144,400	3.5		Weld

X-ray - Both welds had porosity.

TABLE 5-6

AUTOMATIC MIG WELDING PROCEDURES

Material:	1" HY-130 Plate		
Filler Wire:	.030" diameter Oxweld 83, Heat X42470		
Shielding Gas (cubic feet/hour)			
Backup:	10 CFH, Argon		
Torch:	40 CFH, Argon + 2% O_2		
Root Spacing:	1/16 inch, butt joint		
Pass No	1	2-14	15
Voltage (volts)			
Setting	AC-2.7	AD-4.8	AD-4
Reading	25	26	25
Current (amperes)			
Setting	100	100	100
Reading	100	120	100
Torch Travel (in/min)			
Setting	17	5	12.5
Speed	17	5	12.5
Wire Extension (inches)	5/8	5/8	5/8
Heat Input (joules per in)	9,000	14,000	12,000
Cabinet Controls			
Inching	35	35	35
Range	Low	Low	Low
Burnback	6	6	6
Slope	2	2	2
Preheat (°F)	200		200
Max Interpass Temp (°F)		230	

No tensile tests were conducted due to the poor quality of the weld.

LTV VOUGHT AERONAUTICS DIVISION

TABLE 5-7
AUTOMATIC MIG WELDING PROCEDURES

Material:	1" HY-130 Plate
Filler Wire:	0.045" diameter Oxweld 83, Heat 62613E
Shielding Gas (cubic feet per hour)	
Backup:	Argon, 10 CFH, First pass only
Torch:	Argon + 2% O_2, 50 CFH
Root spacing for first weld pass:	0.062", butt joint

Pass Number	1	2-15	16
Voltage (volts):			
Setting	AD-2	AD-5.5	AD-5.5
Reading	22	25	25
Current (amperes)			
Setting	90	90	90
Reading	180	200	200
Torch Travel (in/min)			
Setting	20	11	13
Speed	20	11	13
Wire Extension (in)	3/4	3/4	3/4
Heat Input (joules per in)	12,000	27,000	23,000
Cabinet Controls			
Inching	35	35	35
Range SW	Low	Low	Low
Burnback	6	6	6
Slope	2	2	2
Preheat (^{o}F):	200	200	200
Max. Interpass Temp (^{o}F)		225	
Remarks			Sealing pass back side.

Tensile Tests (psi):

Specimen	Fty	Ftu	e	R.A.	Failure
1	111,500	119,000	5	24.6	Weld
2	114,000	122,000	6	24.9	Weld

LTV VOUGHT AERONAUTICS DIVISION

TABLE 5-8

AUTOMATIC MIG WELDING PROCEDURES

Material:	1" HY-130 Plate		
Filler Wire:	.062" diameter Oxweld 83, Heat R31439		
Shielding Gas (cubic feet/hour)			
Backup:	10 CFH, Argon		
Torch:	50 CFH, Argon + 2% O_2		
Root Spacing:	1/16 inch, butt joint		
Pass No.	1	2-3	4-17
Voltage (volts)			
Setting	AD-6	BC-5	BC-5
Reading	25	32	32
Current (amperes)			
Setting	80	80	80
Reading	290	300	300
Torch Travel (in/min)			
Setting	20	12.5	16
Speed	20	12.5	16
Wire Extension (inches)	3/4	5/8	5/8
Heat Input (joules per in)	22,000	46,000	36,000
Cabinet Controls			
Inching	35	35	35
Range	Low	Low	Low
Burnback	6	6	6
Slope	2	2	2
Preheat (°F)	150		
Max Interpass Temp (°F)		175	175

Tensile Tests (psi)

Specimen No.	Fty	Ftu	e	Failure
1	120,900	128,900	7	Weld
2	124,600	130,100	10	Weld
3	126,000	126,700	5	Weld

TABLE 5-9
AUTOMATIC MIG WELDING PROCEDURES

Material: 1" HY-130 plate

Filler Wire: 0.062" diameter "Special" Airco Wire, Heat 9376

Shielding Gas: (cubic feet/hr):

Backup: Argon, 10 CFH, First pass only

Torch: Argon + 2% O_2 50 CFH

Root spacing for first weld pass: 0.062", butt joint

Plate Number	3				4	
Pass Number	1	2	3-15	16	1	2-14
Voltage (volts):						
Setting	BC-3.5	BC-5	BC-3	BC-3	BC-3.5	BC-5
Reading	28	30	28	28	28	30
Current (amperes):						
Setting	90	85	85	80	90	85
Reading	320	320	310	280	320	310
Torch Travel (in/min):						
Setting	20	12.5	16	21	20	14.2
Speed	20	12.5	16	21	20	14.2
Wire Extension (in)	3/4	3/4	3/4	3/4	3/4	3/4
Heat Input (joules/inch)	26,800	46,000	32,500	22,400	26,800	40,000
Cabinet Controls						
Inching	35	35	35	35	35	35
Range SW	Low	Low	Low	Low	Low	Low
Burnback	6	6	6	6	6	6
Slope	2	2	2	2	2	2
Preheat (°F)	300			300	400	
Max. Interpass Temp. (°F)		325	325			425
Remarks	X-ray inspection revealed transverse cracking.			Sealing pass back side.	X-ray inspection no cracking.	

TABLE 5-10
AUTOMATIC MIG WELDING PROCEDURES

Material:	1" HY-130 plate
Filler Wire:	0.062" diameter "Special" Airco Wire, Heat R9376
Shielding Gas (cubic feet/hour)	
Backup:	Argon, 10 CFH, First pass only
Torch:	Argon + 2% O_2, 50 CFH
Root spacing for first weld pass:	0.062", butt joint

Plate Number		1			2	
Pass Number	1	2&3	4-16	1	2&3	4-15
Voltage (volts):						
Setting	BC-3.5	BC-5	BC-3	BC-3.5	BC-5	BC-5
Reading	28	30	28	28	30	30
Current (amperes):						
Setting	92	80	85	92	65	85
Reading	330	300	300	330	300	340
Torch Travel (in/min):						
Setting	20	12.5	15	20	12.5	15
Speed	20	12.5	16	20	12.5	16
Wire Extension (in)	3/4	3/4	3/4	3/4	3/4	3/4
Heat Input (joules/in)	27,700	43,200	31,500	27,700	43,200	38,000
Cabinet Controls						
Inching	35	35	35	35	35	35
Range SW	Low	Low	Low	Low	Low	Low
Burnback	[illegible]	6	6	6	6	6
Slope	2	[illegible]	2	2	2	
Preheat (°F)	200			200		
Max. Interpass Temp (°F)		225	225		225	225
Remarks	X-ray inspection revealed transverse cracking.			X-ray inspection revealed transverse cracking.		

TABLE 5-11

AUTOMATIC MIG WELDING PROCEDURES

Material:	1", HY-130 Plate			
Filler Wire:	.045" diameter Airco 608, Heat S6364			
Shielding Gas (cubic feet/hr)				
Backup:	None			
Torch:	50 CFH Argon + 2% O_2			
Root Spacing:	3/8" butt joint			
Pass No.	1-4	5-6	7-9	10-26
Voltage (volts):				
Setting	AD-5	AD-6.7	AD-6.7	AD-8.2
Reading	25	26	26	27
Current (amperes):				
Setting	92	92	92	100
Reading	180	200	200	240
Torch Travel (in/min)				
Setting	16	16	15	15
Speed	16	16	15	15
Wire Extension (in)	5/8	5/8	5/8	5/8
Heat Input (joules per in.)	17,000	19,500	21,000	26,000
Cabinet Controls				
Inching	35	35	35	35
Range	Low	Low	Low	Low
Burnback	4	4	4	4
Slope	2	2	2	2
Preheat (^{o}F):	225			
Max Interpass Temp (^{o}F)		235	240	240

Tensile Test (psi)

Specimen No.	Fty	Ftu	e	R.A.	Failure
1	121,000	127,000	4	17.3	Weld
2	120,900	129,100	4.5	20.5	Weld

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TABLE 5-12

AUTOMATIC MIG WELDING PROCEDURES

Material: 1" HY-130 Plate

Filler Wire: 0.045" diameter Oxweld 83, Heat 626138

Shielding Gas (cubic feet/hour)

Backup: Argon, 10 CFH, First pass only

Torch: Argon + 2% O_2, 50 CFH

Root spacing for first weld pass: 0.062", butt joint

Plate Number	1		2		3	
Pass Number	2	1&3-25	1	2-20	1	2-22
Voltage (volts):						
Setting	AD-2	AD-5.3	AD-2	AD-5.3	AD-2	AD-5.3
Reading	22	25	22	25	22	25
Current (amperes)						
Setting	90	92	90	92	90	92
Reading	180	200	180	200	180	200
Torch Travel (in/min)						
Setting	20	20	20	15.8	20	15.8
Speed	20	20	20	15.8	20	15.8
Wire Extension (in)	3/4	3/4				
Heat Input (joules per in)	12,000	15,000	12,000	19,000	12,000	19,000
Cabinet Controls						
Inching	35	35	35	35	35	35
Range SW	Low	Low	Low	Low	Low	Low
Burnback	6	6	6	6	6	6
Slope	2	2	2	2	2	2
Preheat (°F)	150		100		150	
Max Interpass Temp (°F)		170		120		170
Tensile Tests (psi)						
Fty	129	129.3	[illegible]	133	130	127.9
Ftu	131	133.9	138	138	136.9	136.9
e	6	7.5	4	5	4	6
R.A.	16	18.5	18.7	22.2	18.3	18.9
Failure	Weld	Weld	Weld	Weld	Weld	Weld

TABLE 5-13
AUTOMATIC MIG WELDING PROCEDURES

Material:	1" 7Al-2Cb-1Ta Titanium Plate for preliminary tensile test specimens		
Filler Wire:	.062" diameter 7Al-2Cb-1Ta titanium, Heat X2469		
Shielding Gas (cubic feet/hour)			
Backup:	10 CFH, Argon		
Torch:	50 CFH, Argon		
Shield:	90 CFH, Argon		
Root Spacing:	1/16" butt joint		
Pass No.	1	2-4	5-7
Voltage (volts)			
Setting	BC-4	BC-6	BC-6
Reading	31	31	30
Current (amperes)			
Setting	100	100	100
Reading	250	280	300
Torch Travel (in/min)			
Setting	18	11	11
Speed	18	11	11
Wire Extension	3/4	5/8	5/8
Heat Input (joules per in)	26,000	47,500	49,000
Cabinet Controls			
Inching	35	35	35
Range	Low	Low	Low
Burnback	2	2	2
Slope	2	2	2
Preheat (°F)	RT		
Max Interpass Temp. (°F)		250	250

Tensile Tests (psi

Specimen No.	Fty	Ftu	e	R.A.	Failure
1	110,600	124,000	14	30	PM
2	110,200	124,000	14	23.5	W

PM = Parent Metal
W = Weld

TABLE 5-14
AUTOMATIC MIG WELDING PROCEDURES

Material:	1" Ti 7Al-2Cb-1Ta Titanium Plate for 5" diameter patch test specimens		
Filler Wire:	.062" diameter Ti 7Al-2Cb-1Ta Titanium		
Shielding Gas (cubic feet/hour)			
Backup:	5 CFH, Argon		
Torch:	50 CFH, Argon		
Shield:	90 CFH, Argon		
Root Spacing:	1/16"		
Pass No.	1	2-4	5-6
Voltage (volts)			
Setting	BC-6	BC-6	BC-6
Reading	33	32	31
Current (amperes)			
Setting	100	100	100
Reading	250	280	300
Torch Travel (in/min)			
R.P.M.	1.15	.7	.7
Speed	18	11	11
Wire Extension (inches)	3/4	5/8	5/8
Heat Input (joules per in)	27,000	49,000	49,000
Cabinet Controls			
Inching	35	35	35
Range	Low	Low	Low
Burnback	2	2	2
Slope	2	2	2
Preheat (°F)	RT		
Max Interpass Temp (°F)		250	250

Weld Results

These parameters resulted in a good weld with a minimum of porosity.

TABLE 5-15

AUTOMATIC MIG WELDING PROCEDURES

Material:	1/2" 7Al-2Cb-1Ta Titanium Plate for 5" diameter patch test specimen	
Filler Wire:	.062" diameter 7Al-2Cb-1Ta Titanium	
Shielding Gas (cubic feet/hour)		
Backup:	15 CFH, Argon	
Torch:	50 CFH, Argon	
Shield:	90 CFH, Argon	
Root Spacing:	1/16 inch	
Pass No.	1	2
Voltage (volts)		
Setting	BD-4.5	BD-1.5
Reading	35	33
Current (amperes)		
Setting	100	100
Reading	300	300
Torch Travel (in/min)		
R.P.M.	1.1	.51
Speed	17	8
Wire Extension (inches)	5/8	5/8
Heat Input (Joules per in)	37,000	74,000
Cabinet Controls		
Inching	35	35
Range	Low	Low
Burnback	2	2
Slope	2	2
Preheat (°F)	RT	
Max Interpass Temp (°F)		250

Weld Results:

These parameters resulted in a good weld with a minimum of porosity.

TABLE 5-16

AUTOMATIC MIG WELDING PROCEDURES

Material:	1" 7Al-2Cb-1Ta Titanium Plate for all final test specimens	
Filler Wire:	0.62" diameter 7Al-2Co-1Ta Titanium	
Shielding Gas (cubic feet/hour)		
Backup:	10 CFH, Argon	
Torch:	60 CFH, Argon	
Shield:	100 CFH, Argon	
Root Spacing:	3/8" - 25° Bevel Angle - 1/16" Land, butt joint (Use 1/8" thick shim under center of joint to offset warpage.)	
Pass No.	1 & 3-11	2
Voltage (volts)		
Setting	BC-7	BC-7
Reading	31	29
Current (amperes)		
Setting	95	95
Reading	290	320
Torch Travel (in/min)		
Setting	5.4	4.9
Travel	18	16
Wire Extension (inches)	5/8	5/8
Heat Input (joules per in)	30,000	35,000
Cabinet Controls		
Inching	35	35
Range	Low	Low
Burnback	2	2
Slope	2	2
Preheat (°F)	RT	
Max Interpass Temp (°F)	250	250

Weld Results

These parameters resulted in a good weld with a minimum of porosity.

TABLE 5-17

AUTOMATIC MIG WELDING PROCEDURES

Material:	1/4" Ti 7Al-2Cb-1Ta Titanium Plate
Filler Wire:	.062" diameter, 7Al-2Cb-1Ta Titanium
Shielding Gas (cubic foot/hour)	
Backup:	10 CFH, Argon
Torch:	60 CFH, Argon
Shield:	100 CFH, Argon
Root Spacing:	1/16" - 25° Bevel Angle - 1/16" Land, butt joint

Pass No.	1
Voltage (volts)	
Setting	BC-6.8
Reading	31
Current (amperes)	
Setting	100
Reading	350
Torch Travel (in/min)	
Setting	5.9
Travel	20
Wire Extension (inches)	5/8
Heat Input (joules per in)	32,500
Cabinet Controls	
Inching	35
Range	Low
Burnback	2
Slope	2
Preheat (°F)	RT

Weld Results:

These parameters resulted in a good weld with a minimum of porosity.

TABLE 5-18

AUTOMATIC MIG WELDING PROCEDURES

Material: 1-3/8" 17-4PH Stainless Steel Casting

Filler Wire: .045" diameter 17-4PH stainless steel

Shielding Gas (cubic feet/hour)

Backup: 15 CFH, argon

Torch: 30 CFH argon for 1st through 5th passes; 30 CFH argon + 2% O_2 for 6th through 13th passes

Root Spacing: 1/16 inch, butt joint

Pass No.	1	2	6	7-13
Voltage (volts)				
Setting	BC-6	BC-5	BC-4.5	BC-4.5
Reading	32	32	30	30
Current (amperes)				
Setting	90	90	85	85
Reading	300	220	300	300
Torch Travel (in/min)				
Setting	5.4			5.4
Travel	18	10.7	10.7	18
Wire Extension (in)	3/4	3/4	3/4	3/4
Heat Input (joules per inch)	32,000	39,400	50,500	30,000
Cabinet Controls				
Inching	35	35	35	35
Range	Low	Low	Low	Low
Burnback	6	6	6	6
Slope	2	2	2	2
Preheat (°F)	none			
Remarks:				Pass #13 was sealing pass on back side.

Weld Results:

Internal cracks were found in weld during machining of test specimens.

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TABLE 5-19
MANUAL TIG WELDING PROCEDURES

Material:	1-3/8" 17-4PH Stainless Steel Casting				
Filler Wire:	.062" diameter 17-4PH Stainless Steel				
Shielding Gas (cubic feet/hour)					
Torch:	18 CFH, Argon				
Root Spacing:	1/16" - 25° Bevel Angle - 1/16" Land, butt joint				
Trial No.	1	2		3	
Pass No.	1	1	2	1	2
Voltage (volts)	18-20	18-20		18-20	18-20
Current (amperes)	180-200	180-200		180-200	180-200
Preheat (°F)	None	275		None	
Max. Interpass Temp. (°F)			450		300
% Filler Wire	10	20	20	80	80
Results	Centerline Cracking	Centerline Cracking Both Passes		Several Short (1/4") Center-Line Cracks	Good

Trial No.	3	3
Pass No.	3-10	11 to completion
Voltage (volts)	18-20	18-20
Current (amperes)	180-200	180-200
Preheat (°F)	---	---
Max. Interpass Temp (°F)	275-325	275-325
% Filler Wire	---	---
Results	Good - Plate Warped 21.5°	Good Weld

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TABLE 5-20
AUTOMATIC MIG WELDING PROCEDURES

Material:	1-3/8" CD-4 MCu Plate			
Filler Wire:	.062" diameter, CD-4 MCu, Heat W10067			
Shielding Gas (cubic feet/hour)				
Backup:	15 CFH, Argon			
Torch:	50 CFH, Argon + 2% O_2			
Root Spacing:	1/16-inch, butt joint			
Pass No.	1	2	3-5	6-10
Voltage (volts)				
Setting	BC-1.5	BC-2.5	BC-2.5	BC-4.5
Reading	30	27	27	30
Current (amperes)				
Setting	85	87	87	87
Reading	300	300	290	300
Torch Travel (in/min)				
Setting	18	10.7	9	9
Speed	18	10.7	9	9
Wire Extension (inches)	3/4	3/4	5/8	5/8
Heat Input (joules per in)	30,000	44,000	48,000	60,000
Cabinet Controls				
Inching	35	35	35	35
Range	Low	Low	Low	Low
Burnback	6	6	6	6
Slope	2	2	2	2
Preheat (°F)	RT			
Max Interpass Temp (°F)				300

Weld Results:

Internal cracks were found in weld during machining of test specimens.

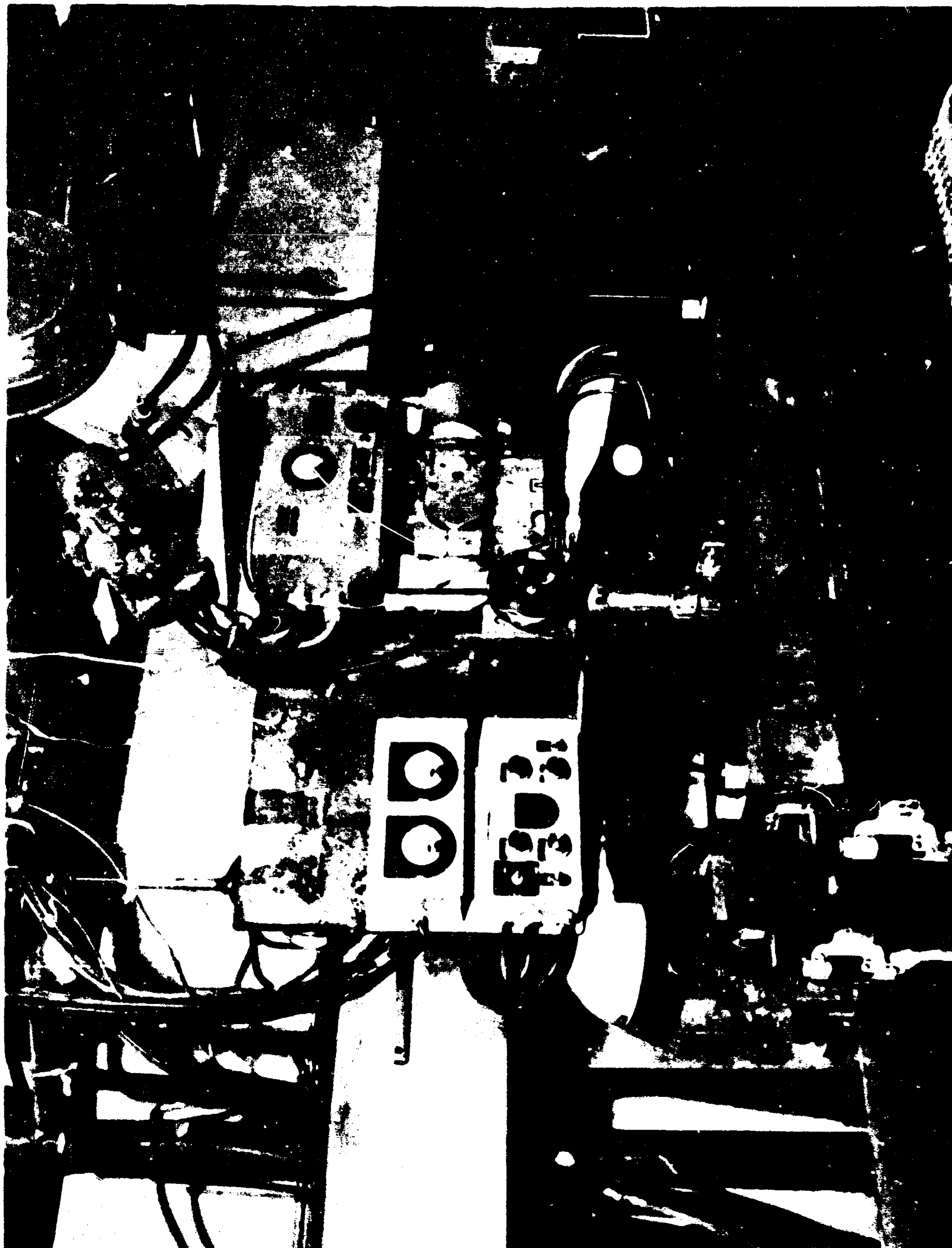


Figure 5.07 Equipment used for MIG (metal inert gas) welding, showing the tool used to hold the plates during welding.

Figure 5.08 Closeup view of a HY-130 steel plate before welding, with torch in position for the first or root pass.

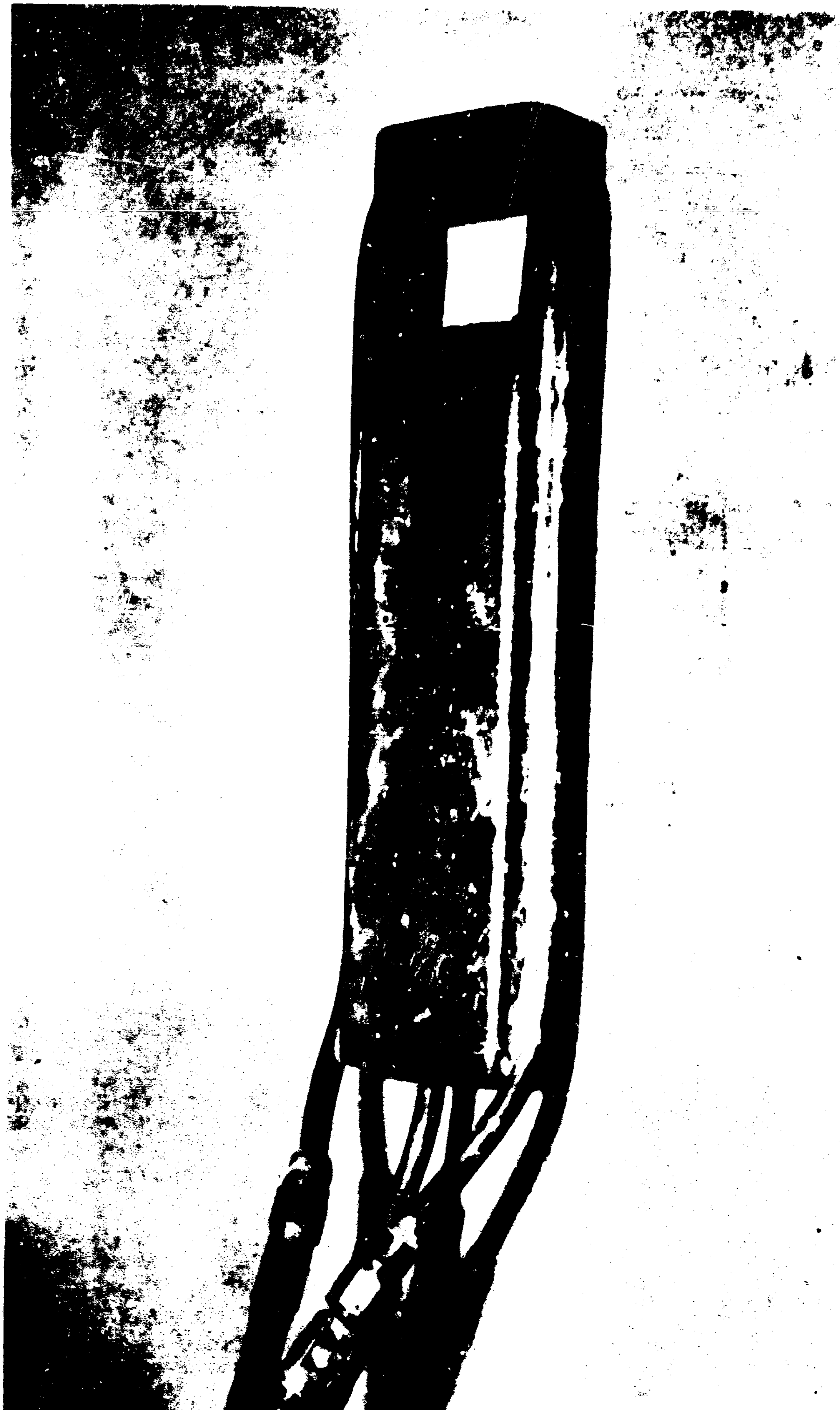
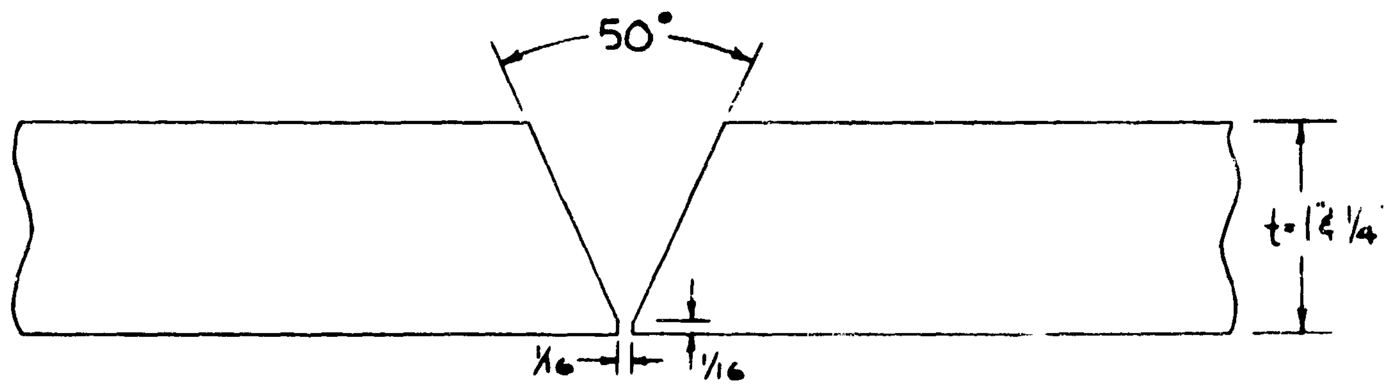


Figure 5.09 View of water cooled trailer shield used for welding 7-2-1 titanium test specimens.

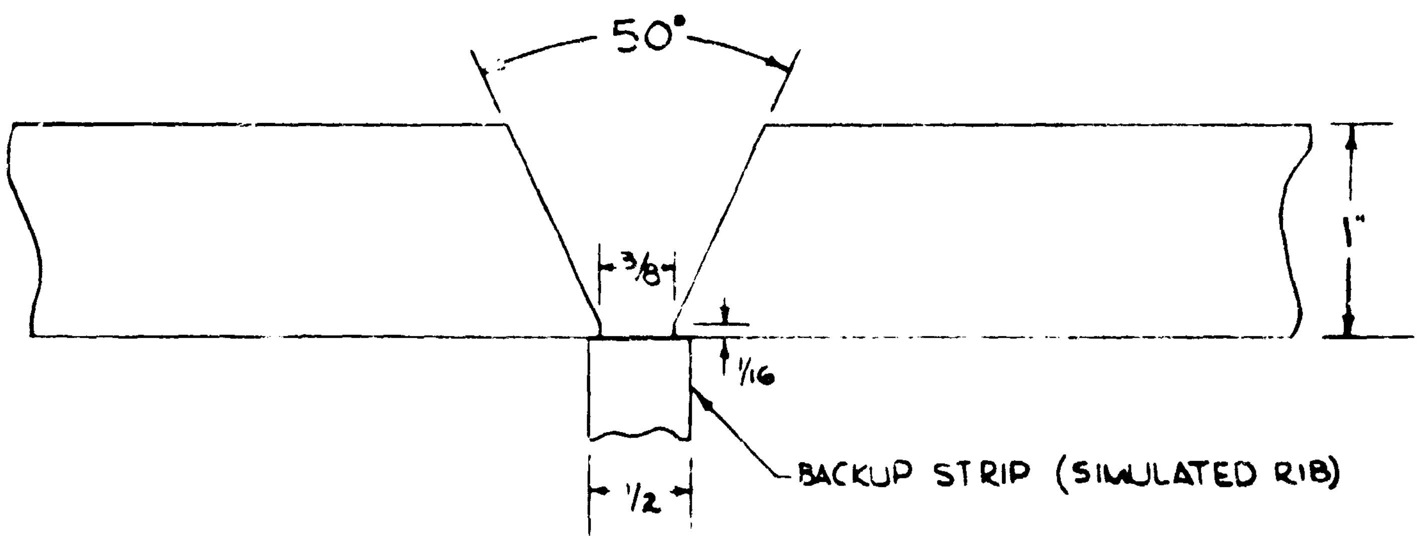
FIGURE 5.10

WELD GROOVE GEOMETRY

(USED FOR WELDING HY-130 AND Ti-7Al-2Cb-1Ta, BOTH 1" & 1/4" PLATES)



GROOVE NO. 1



GROOVE NO. 2

Figure 5.11 Cross section of a MIG weld in 1 inch HY-130 plate with a 3/8 root spacing and a 1/2 X 1/2 inch simulated rib. 3.5X

Figure 5.12 Cross section of a MIG weld in a 1 inch thick titanium plate with a 3/8 inch root spacing and a 1/2 by 1 inch simulated rib. 3.5X

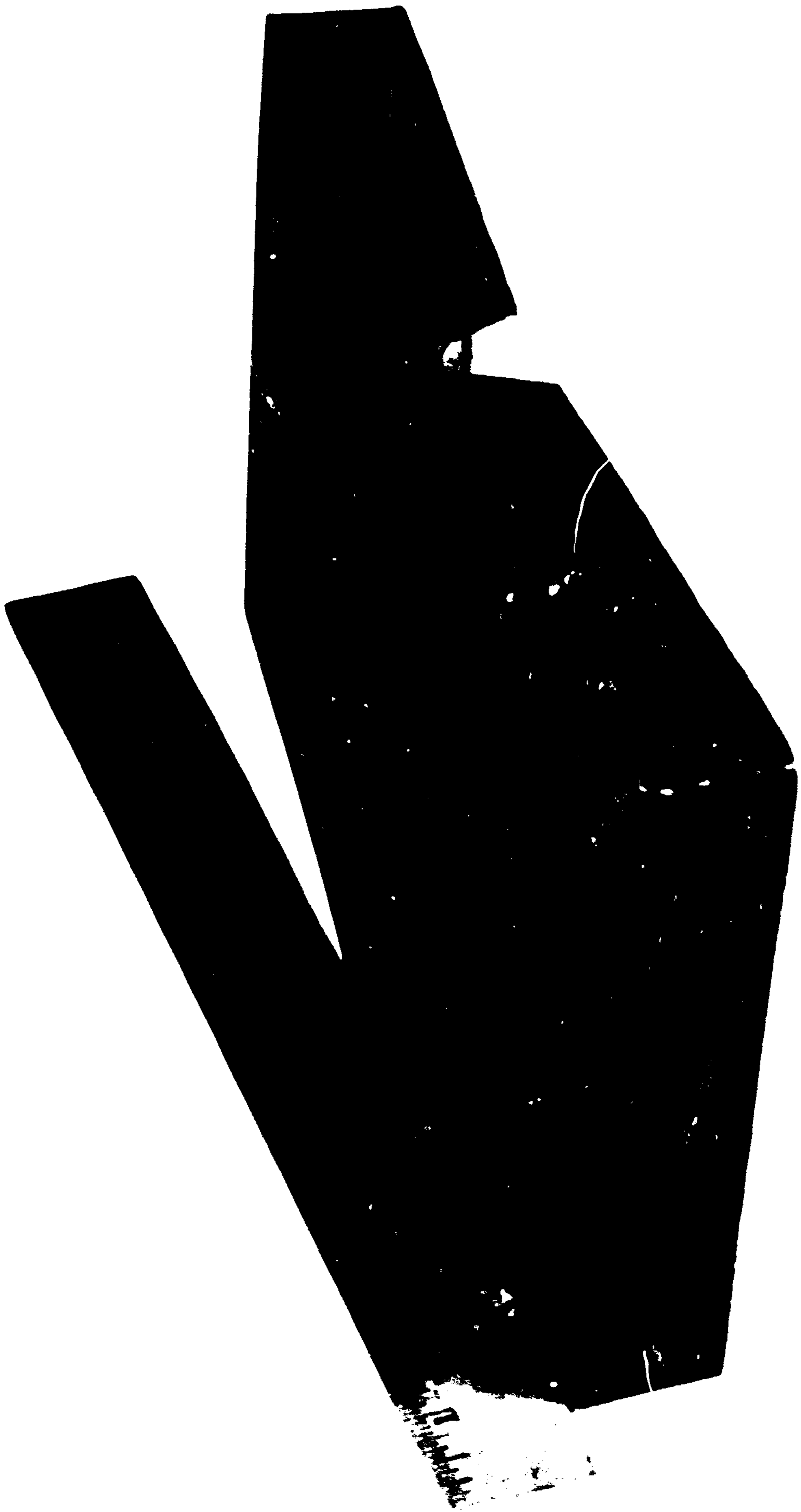


Figure 5.13 View showing warping of a 1-3/8 inch thick 17-4PH stainless steel when manually TIG welded under no restraint. Plate was positioned at a 12° reverse angle before welding and warped to a 9-1/2° positive angle when groove was filled to a depth of 5/8 inch with filler metal.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 MIL-S-16216 (HY 130)

Heat treated to the 130-150 KSI yield strength range and protected with a coating, MIL-S-16216 (HY 130) is a suitable material for a 90 knot hydrofoil construction.

6.2 MOSITE 60125

Uncured neoprene stock with a Shore A hardness of 70 cured in place on the foil in an 0.080 inch thickness will resist 30 days exposure to 90 knot impingement erosion and cavitation erosion of 150 fps velocity in the NASL rotating disc test.

6.3 Ti 7Al-2Cb-1Ta

Titanium 7Al-2Cb-1Ta is a desirable material for hydrofoils in toughness, strength to weight ratio, and resistance to impingement and static corrosion. It can be economically fabricated into foils by standard production methods. The shortcomings of this alloy are that it has a lower corrosion fatigue life than expected, is subject to stress corrosion cracking under high stress concentrations in a marine environment, and has a high metal loss rate under severe cavitation conditions. The advantages potentially available in a titanium foil and strut thus cannot be obtained without alloy modifications.

6.4 17-4PH CASTINGS

Precipitation hardening stainless steel 17-4PH castings with the chemistry used in this program and given a H-1100 age is a suitable material for experimental foil castings.

6.5 CD4MCu CASTINGS

This alloy stress corrosion cracks under a variety of heat treatments and chemistries, so that in its present state, it is not suitable for experimental foils and struts which would be subject to constant stresses.

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APPENDIX A

PHASE I AND II DATA SUMMARY

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APPENDIX A

TABLE OF CONTENTS

1.0 PHASE I DATA SUMMARY

1.1 INTRODUCTION

A summary of the most significant parameters for Ti-6Al-4V, Ti-8Al-2Cb-1Ta, AISI 4330M and HY 100 compiled during the Phase I literature survey are presented in Table 1-1.

TABLE [illegible]
[illegible] DATA SUMMARY
[illegible] PARAMETERS FOR [illegible] PHASE II MATERIAL

[illegible]	[illegible] PROPERTIES	[illegible] PROPERTIES	PRODUCTIBILITY	COMMENTS
[illegible]	[illegible]	[illegible] - 0.4 [illegible] (3) [illegible]	Min. [illegible] radius approximatel [illegible] 5t. (5) Silver aluminum allo s suitable for brazing. TIG and resistance spot welding applicable. Casting in experimental stage. Machining fair to difficult depending on heat treat condition.	Corrosion resistance expected to be excellent.
[illegible]	[illegible]		[illegible] Index estimated about 3C, fair. Should be able [illegible]. Casting in experimental stage. [illegible] weldable [illegible] aircromatic, heliarc and resistance methods. ( ) Silver-aluminum alloys suitable for brazing. Fair forming at room temperature. Min. bend [illegible] to 3t. ( )	Corrosion resistance expected to be excellent.
[illegible]	[illegible]	[illegible] tested [illegible]		
[illegible]	[illegible]	[illegible]		Similar to [illegible]

* [illegible]

[illegible] Temperature

** [illegible]

*** [illegible]

( ) Reactive Metals, Inc. [illegible] Data Sheet: [illegible]

( ) American [illegible] Metals Handbook, Vol. I, [illegible] Selection [illegible]

( ) [illegible] Report [illegible] Investigation of the [illegible] Properties of [illegible] Steels, [illegible] March [illegible]

( ) [illegible] Report [illegible]

( ) [illegible] Steel [illegible] for H [illegible] [illegible] Steels [illegible]

2.0 PHASE II DATA SUMMARY

2.1 INTRODUCTION

The following tables and figures present all pertinent data developed during Phase II and early Phase III testing for Ti 6Al-4V, Ti8Al-2Cb-1Ta, AISI 4330M and HY 130. This information is not considered adequate for design purposes and should not be used as such. Every effort has been made, however, to make all data presented as complete as possible by including and referencing information concerning test method, heat treatment procedures, welding procedures, material chemical composition, and coating application methods.

Section 2.5 has been expanded to include all sea water static corrosion data accumulated during Phases II and III. Although most of the data are for materials not evaluated in Phase III, the amount and nature of the data makes complete reporting imparative.

Section 2.10 includes static immersion, sea water impingement, and cavitation-erosion data for all coating systems evaluated in Phase II. Static immersion and cavitation-erosion tests were performed on a relatively small number of coating systems and all details of the systems are included. A large number of coating systems were tested for resistance to high velocity sea water impingement, and, although complete details of each system are not presented, sufficient information is included to indicate the general performance characteristics of the various systems when classified by generic type, thickness, hardness, surface preparation and application method.

2.2 TENSILE PROPERTIES

Tensile properties for 0.050 inch and 0.250 inch Phase II steel and titanium alloys are presented in Table 2-1. These data were used to establish a base line of 10 percent elongation in 2 inches from which other properties of the material were compared and to obtain the tensile yield of 0.050 inch material for the calibration of stress corrosion specimens.

Data presented in Tables 2-2 and 2-3 were obtained during the Phase II supplemental program to permit additional comparisons of the materials.

Table 2-4 indicates the effects of interstitial chemistry and tempering temperature on the tensile properties of Ti 6Al-4V. Tables 2-5 and 2-6 present data concerning the effects of tempering temperature and time on the tensile properties of HY 130 and AISI 4330M.

Additional tensile data for Phase III materials are presented in Section 4.1 of the basic report.

TABLE 2-1

TENSILE TEST DATA FOR STEEL AND TITANIUM ALLOYS

MATERIAL (1)	MATERIAL THICKNESS (IN.)	TYPE SPECIMEN (2)	F_{ty} (KSI)	F_{tu} (KSI)	ELONG. (% IN 2 INCHES)	HARDNESS (R_c)
TI 6AL-4V	0.050	Unwelded	141.3 (3)	147.5	10.7	35
AISI 4330M FOR COATING	0.050	Welded (4)	180.4	209.6	3.6	38
AISI 4330M FOR COATING	0.250 0.250	Unwelded Welded	168.8 181.7	209.9 202.9	10.1 8.7	38 38
AISI 4330M FOR CLADDING	0.050	Unwelded	134.[illegible]	142.6	.1	
HY 100 FOR CLADDING	0.050	Unwelded	116.9	130.3	16.1	R_b 95

(1) Heat treatment per Table 1, Appendix D; composition per Table 1, Appendix C; and welding per Section 2.0, Appendix D, Reference 2.

(2) ASTM E-8-61T standard rectangular test specimen with 2 inch gage length.

(3) All values are average of three (3) specimens, longitudinal test.

TABLE 2-2

TENSILE TEST DATA FOR WELDED, 1.0 INCH TI 6AL-4V AND AISI 4330M FOR COATING

MATERIAL (1)	SPEC. NO. (2)	F_{ty} (KSI)	F_{tu} (KSI)	% ELONGATION IN 4 INCHES	% ELONGATION IN 5 INCHES	% ELONGATION IN 8 INCHES	FAILURE LOCATION
TI 6AL-4V	1	122.9	133.1	2.8	—	—	Weld
	2	117.6	133.6	2.2	—	—	Weld
	AVG.	120.2	133.4	2.5			
AISI 4330M FOR COATING	1	149.1	167.0	—	2.3	2.4	HAZ
	2	142.9	160.5	3.0	—	1.0	HAZ
	3	146.1	159.7	—	4.0	1.8	HAZ
	AVG.	146.0	162.4	3.0	3.4	1.7	

(1) Heat treatment per Table 3.18, composition per Table 3.19 and welding per Tables 3.11 and 3.15 of Reference 3.

(2) ASTM E-8-61T standard rectangular test specimen with 8 inch gage length.

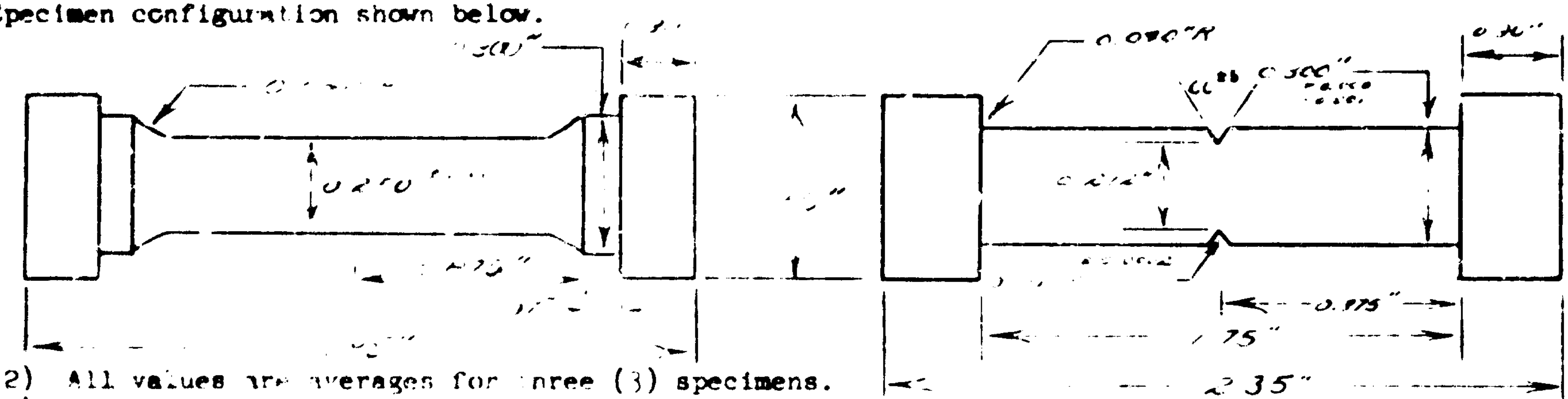
TABLE 2-3

NOTCHED AND UNNOTCHED TENSILE DATA FOR WELDED TITANIUM AND STEEL ALLOYS

MATERIAL (1)	UNNOTCHED					NOTCHED	
	ELONGATION (% IN 2 INCHES)	REDUCTION IN AREA (%)	MODULUS (PSI x 10^{-6})	F_{ty} (KSI)	F_{tu} (KSI)	F_{tu} (KSI)	NOTCHED / UNNOTCHED RATIO
TI 6AL-4V	7.3 (2)	18.3	15.7	134.5	151.7	204.9	1.35
TI 8AL-2CB-1TA	10.0	21.1	15.6	118.7	133.7	193.6	1.45
AISI 4330M	7.7 (3)	50.6	30.1	158.0	161.3	261.2	1.62
HY 100	13.7 (3)	64.3	29.7	96.5	110.0	176.4	1.77

(1) Heat treatment per Table 3.18, composition per Table 3.19 and welding per Tables 3.11, 3.14, 3.16 and 3.17 of Reference 3.

Specimen configuration shown below.



(2) All values are averages for three (3) specimens.
(3) Unnotched specimens failed outside of welded section.

TABLE 2-4

TENSILE AND CHARPY V NOTCH TEST DATA FOR TI 6AL-4V AND TI 8AL-2CB-1TA

MATERIAL	INTERSTITIAL CHEMISTRY (%)				AGING TEMP. FOR 1 HR. (°F) (1)	F_{ty} (KSI)	F_{tu} (KSI)	ELONG. (%)	CHARPY V NOTCH FRACTURE ENERGY AT 32°F (FT.-LB.) (3)
	O_2	C	N_2	H_2 (ppm)					
TI 6AL-4V (MI) (4)	0.12	0.02	0.01	40/60	1725 1750 1775 1800 1825 1850	132.2[2] 137.4 131.8 130.4 133.8 134.0	140.8 140.2 140.5 141.5 141.4 141.4	12 12 11 11 10 12	23 23 23 22 24 19
TI 6AL-4V (ELI) (5)	0.06	0.025	0.01	—	1750 1825	105.3 106.1	126.0 127.9	— —	30 32
TI 6AL-4V (MI) (4)	0.12	0.02	0.01	40/60	Hot Rolled & Annealed Only	132.8[6]	138.4	18.3	—
TI 8AL-2CB-1TA	—	—	—	—	(7)	—	—	—	Welded - 41 Unwelded - 26

(1) Hot rolled and annealed before aging, air cooled after aging.
(2) 1/4" round specimen, longitudinal test.
(3) ASTM E-23-60, Type A specimen.
(4) Medium interstitial.
(5) Extra low interstitial.
(6) 1/8" x 1" rectangular specimen.
(7) 1825°F - 1 hr., air cool, 1075°F - 8 hrs, air cool. Welded by Reactive Metals, Inc.
(8) Composition per Table 4-17 basic report.

TABLE 2-5

TENSILE TEST DATA FOR UNWELDED HY 130 USING VARIOUS TEMPERING TEMPERATURES AND TIMES

TEMPERING TEMPERATURE (°F) (1)	TIME AT TEMPERATURE (HRS.)	F_{ty} (KSI)	F_{tu} (KSI)	ELONGATION (%)	REDUCTION IN AREA
1070	2	138.7[2]	149.8	18.0	62.8
1070	8	127.1	138.3	19.0	66.0
1075	2	141.5[3]	161.5	17.0	62.7
1080	2	138.3	148.3	17.0	65.0
1080	4	116.3	137.9	20.0	70.5
1080	6	113.4	126.7	20.0	73.5
1085	2	136.0	160.3	17.5	63.2
1085	4	139.9	150.0	18.5	63.4
1090	2	136.0	147.8	18.0	64.1
1090	4	121.3	133.4	19.0	68.5
1095	2	132.0	142.7	18.5	67.5
1095	6	116.8	130.3	19.5	70.5
1100	2	109.5	125.3	20.0	64.6

(1) Material quench hardened before tempering. See Table 4-17 for compositions.

(2) Average values for 2 specimens except as noted. All specimens 1/2" diameter.

(3) Average values for 4 specimens.

TABLE 2-6

TENSILE TEST DATA FOR UNWELDED AISI 4330M
USING VARIOUS TEMPERING TEMPERATURES

TEMPERING TEMPERATURE (°F) (1)	F_{ty} (KSI)	F_{tu} (KSI)	ELONGATION (%)	REDUCTION IN AREA (%)
950	189.9 (2)	198.4	14.8	55.0
1000	181.8	189.8	15.7	57.4
1050	185.1	193.8	16.0	57.1
1100	172.7	179.9	15.7	57.9
1200	131.1	142.1	18.3	62.3
1250	112.3	123.5	20.7	65.0

(1) Material received the following heat treatment before double tempering for 4 hours at indicated temperature:

a. 1550 - 1625°F
b. Oil Quench
c. 850°F - 2 hrs., air cool
d. 850°F - 2 hrs., air cool
e. Weld (Above material not welded)
f. 825°F - ? hrs., air cool
g. 925°F - 2 hrs., air cool

See Table 4-17 basic report for material composition.

(2) Average values for 3 specimens. All specimens 1/2" diameter.

2.3 FRACTURE TOUGHNESS

Fracture toughness characteristics were determined by Charpy V Notch impact test using a Tinius-Olsen Impact Tester having a striking velocity of 16.5 ft./sec. Specimens were cooled in dry ice and alcohol and the temperature checked with thermocouples. Screening test data for unwelded and welded material at 0°F are presented in Table 2-7.

Drop-weight nil ductility tests were run on Ti 6Al-4V and the results reported in Table 3-4, reference 3; however, the test method and results are somewhat questionable and the results are not considered valid.

Additional fracture toughness for Phase III materials are presented in Section 4.4 of the basic report.

LTV VOUGHT AERONAUTICS DIVISION

TABLE 2-7

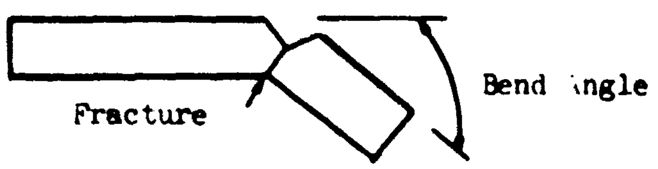
CHARPY V NOTCH IMPACT DATA
(TEST TEMPERATURE - 0°F)

MATERIAL (1)	SPECIMEN TYPE (2)	ASTM E 23-60 SPECIMEN TYPE	ENERGY ABSORBED (FT.-LB.) (3)	BEND ANGLE BEFORE FRACTURE (DEGREES) (4)	TYPE FAILURE (5)
TI 6Al-4V	W (a,d,f)	A (6)	6.7	3	Ductile
	U (a,d,f)	A (7)	15.0	4	Ductile
	W (a,d,f)	A (7)	29 (8)	10	Ductile
TI 8AL-2CB-1TA	W (b,d,f)	A (6)	14.5	4	Ductile
AISI 4330M FOR CLADDING	U (c,e,g)	W (9)	5.0	7	Ductile
AISI 4330M FOR COATING	W (a,d,f)	A (6)	4.3	1	Mixed
	U (a,d,f)	A (7)	16.0	4	Ductile
	W (a,d,f)	A (7)	9.0	4	Mixed
	U (c,e,g)	W (9)	5.1	7	Ductile
HY 100 FOR COATING	W (a,d)	A (6)	23.8	7	Ductile

(1) a. Heat treatment per Table 3.18, Reference 3.
b. Hot rolled and annealed.
c. Heat treatment per Table 1, Appendix D; Reference 2.
d. Composition per Table 3.19, Reference 3.
e. Composition per Table 1, Appendix C; Reference 2.
f. Welding per Tables 3.39, 3.41 and 3.35, Reference 3.
g. Welding per Section 2.0, Appendix D; Reference 2

(2) W - Welded, U - Unwelded Notch perpendicular to original material surfaces.

(3) Bend angle determined per diagram:



(5) Determined by fractured surface appearance and bend angle.

(6) Specimens 0.25" wide from 1/4" plate.

(7) Specimens from 1" plate.

(8) Average of 2 specimens.

(9) Specimens from 1/4" plate.

2.4 BEND DUCTILITY OF WELDS

Bend tests were performed on Ti 6Al-4V to determine the soundness of welds and the quality of fusion to the base metal. The results are presented in Table 2-8.

Comparison of bend angles before fracture indicates a significant decrease for the welded material, however, examination of the specimens shows that plastic deformation was confined to the weld material, but extended over a considerably larger distance for the unwelded material. For this reason the results of this test are not considered evidence of unacceptable mechanical properties of as-welded Ti 6Al-4V.

TABLE 2-8

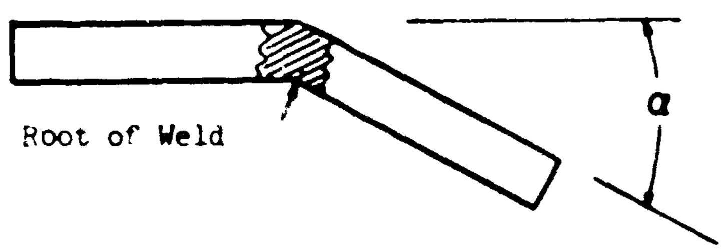
BEND TEST DATA FOR 1.0 INCH, UNWELDED AND WELDED TI 6AL-4V (1)

SPECIMEN NUMBER	TYPE SPECIMEN (2)	BEND ANGLE BEFORE FRACTURE (DEGREES) (3)	LOCATION OF FAILURE
1 (4)	Unwelded	33°	Parent Metal (6)
2 (4)	Unwelded	35°	Parent Metal (6)
3 (5)	Welded	20°	Weld (6)(7)
4 (5)	Welded	20°	Weld (6)(7)

(1) Heat treatment per Table 3-18, Composition per Table 3-19 and Welding per Table 3-15, reference 3.

(2) Specimen 1" x 5" x 10" with transverse weld across 5" width.

(3) Bend angle before fracture (α) measured as follows:



(4) F_{ty} = 138 Ksi

(5) F_{ty} = 120 Ksi

(6) Approximately 9% neck-down on tension side of specimen.

(7) No defects detected in weld.

2.5 STATIC CORROSION

2.5.1 Static corrosion specimens were fabricated by LTV for all unclad and uncoated Phase II materials except CP Ti and exposed in sea water at the International Nickel Company's Harbor Island (Kure Beach) Corrosion Laboratory, Wrightsville Beach, North Carolina. Two unwelded (excluded for Hastelloy C) and two transverse welded specimens 4" x 12" x 1/4" were prepared for the following exposure periods.

a. Removed Monthly
b. 6 Months
c. 12 Months
d. 24 Months
e. 48 Months (not completed)

After fabrication, specimens were marked with material and specimen identification numbers, vapor honed, weighed to the nearest tenth of a gram and the length, width and average thickness determined. At Harbor Island, specimens were mounted in test racks using non-metallic insulators and immersed in sea water below the tidal zone.

2.5.2 SIMULATED MAINTENANCE CORROSION TESTS

Two unwelded and two welded specimens were removed from test every month for 18 months, thoroughly cleaned and examined for (1) corrosion rate, (2) pitting and crevice corrosion, (3) galvanic effects and (4) amount and type of fouling. The maximum, minimum and average water temperatures during the test period were recorded and photographs made of significant damage. Specimens were then returned to test.

2.5.3 CONTINUOUS STATIC EXPOSURE

Specimens for continuous exposure were removed at the end of the test period, cleaned and examined as described above.

2.5.4 RESULTS

Static corrosion data for materials that showed no pitting and only minor crevice corrosion damage are presented in Tables 2-[illegible] through 2-15 for specimens removed at monthly intervals and exposed continuously for 6, 12 and 24 months. Static corrosion rates for these materials are compared in Figure 2.1 and typical specimens after two years continuous immersion are shown in Figures 2.3 and 2.4

Static corrosion data for materials that showed considerable pitting and crevice corrosion damage are presented in Tables 2-16 through 2-27. Static corrosion weight losses for these materials are compared in Figure 2.2. Corrosion rates are not shown because the rates would be misleading due to the un-uniform material loss of the specimens. K Monel and 17-4PH specimens after two years continuous immersion are shown in Figure 2.5 and AM 355 (Cast) and CD 4 MCu (Cast) specimens after one year continuous immersion are shown in Figure 2.6.

The static corrosion data for specimens removed monthly for 18 months were extrapolated to 24 months assuming that exposure conditions and results (water temperature, fouling rate, weight loss, etc.) for the 18 to 24 month period would be the same as for the 6 to 12 month exposure period. This extrapolation permitted a comparison of 24 month continuous immersion data and data for monthly removal specimens projected to 24 months.

Static immersion results for Phase II coating systems are presented in Section 2.10.1, Appendix A and for Phase III coating systems in Section 4.7 of the basic report.

Material compositions are shown in Table 1, Appendix C; heat treatment in Table 1, Appendix D; and welding procedures are outlined on pages 4.03 through 4.20 of reference 2.

TABLE 2.9

MONTHLY [illegible] CORROSION [illegible] (NO PITTING AND MINOR CREVICE CORROSION)

INCONEL [illegible]

MONTHS EXPOSED	UNWELDED SPECIMEN 1			UNWELDED SPECIMEN 2			WELDED SPECIMEN(2) 1			WELDED SPECIMEN 2			% FOULED	AVG WATER TEMP. (°F)
	WT LOSS (GMS)	MC. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MC. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MC. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MC. RATE (MPY)	CREVICE & PITTING CORROSION		
1	0.2	0.2	None	0.2	0.2	None	1.1	[illegible]	None	0.1	0.1	None	10	55
2	0	0		0	0		0		"	0	0	"	40	47
3	0	"	No Pitting (1)		0	No Pitting (1)			No Pitting (1)	0	0	No Pitting (1)	30-40	[illegible]
4	0						0		"	0	0	"	40-50	[illegible]
5	0	0			0	"	0	0	"	0	0	"	20-30	57
6	0	0			0	"	0.1	<0.1	"	0	0	"	30-40	57
7	0	0			0	"	0		"	0	0	"	20-25	74
8	0.1	<0.1			<0.1	"	0	0	"	0.1	<0.1	"	50	77
9	0.3	0.3	"		0		0.3	0.3	"	0.4	0.4	"	40	73
10	0.1	<0.1	"	[illegible]	[illegible]	"	0.1	<0.1	"	0.1	<0.1	"	50	50
11	0	"	"		0	"	0	0	"	0.1	<0.1	"	25	71
12	0	0		0.1	<0.1	"	0		"	0	0	"	5-10	57
13	0	0	"		0	"	0.1	<0.1	"	0.2	0.2	"	5	52
14	0.1	<0.1	"	0.2	0.2		0.2	0.2	"	0	0	"	5	44
15	0	0	"		0	"	0	0	"	0	0	"	0	43
16	0	0	"		0	"	0	0	"	0	0	"	5	48
17	0	0	"	0	0		0	0	"	0	0	"	40	57
18	0.1	<0.1	"	0	0	"	0	0	"	0	0	"	75	64
CUMULATIVE TOTALS														
6	0.2	<0.1	No Pitting(1)	0.2	<0.1	No Pitting(1)	1.2	0.1	No Pitting(1)	0.1	<0.1	No Pitting(1)	--	54
12	[illegible]	<0.1	"	[illegible]	<0.1	"	1.5	0.1	"	0.8	<0.1	"	--	73
18	[illegible]	<0.1		1.2	<0.1		1.9	0.1	"	1.0	<0.1	"	--	55
24*	1.4	<0.1	"	2.0	<0.1	"	2.3	<0.1	"	1.7	<0.1	"	--	73

(1) Incipient crevice corrosion at points of contact with insulators (2) Welded with Inconel 718 filler wire *Extrapolated values

TABLE 2-10

MONTHLY REMOVAL STATIC CORROSION DATA (NO PITTING AND MINOR CREVICE CORROSION)

INCONEL 718 WELDED WITH RENE' 41 FILLER WIRE

MONTHS EXPOSED	WELDED SPECIMEN 1 WT LOSS (GMS)	WELDED SPECIMEN 1 MO. RATE (MPY)	WELDED SPECIMEN 1 CREVICE & PITTING CORROSION	WELDED SPECIMEN 2 WT LOSS (GMS)	WELDED SPECIMEN 2 MO. RATE (MPY)	WELDED SPECIMEN 2 CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	% FOULED	AVG WATER TEMP. (°F)
1	0	0	None	0.1	<0.1	None							5	47
2	0	0	"	0	0	"							20	47
3	0	0	No Pitting (1)	0.1	<0.1	No Pitting (1)							30-40	50
4	0	0	"	0	0	"							10-20	57
5	0.1	<0.1	"	0.1	<0.1	"							40	67
6	0	0	"	0	0	"							20-25	74
7	0.1	<0.1	"	0	0	"							30	77
8	0.1	<0.1	"	0.1	<0.1	"							40	81
9	0	0	"	0	0	"							25	80
10	0.1	<0.1	No Pitting (2)	0.1	<0.1	No Pitting (2)							25	70
11	0	0	"	0	0	"							10-15	5[illegible]
12	0	0	"	0	0	"							5	52
13	0	0	"	0	0	"							5	43
14	0	0	"	0	0	"							0	43
15	0	0	"	0	0	"							5	48
16	0	0	"	0	0	"							30	57
17	0.1	<0.1	"	0.2	0.1	"							75	54
18	0.1	<0.1	"	0	0	"							80	70
CUMULATIVE TOTALS														
6	0.1	<0.1	No Pitting(1)	0.3	<0.1	No Pitting(1)							--	57
12	0.4	<0.1	No Pitting(1,2)	0.5	<0.1	No Pitting(1,2)							--	70
18	0.6	<0.1	"	0.7	<0.1	"							--	54
24*	0.9	<0.1	"	0.9	<0.1	"							--	70

(1) Incipient corrosion at points of contact with insulators.
(2) Incipient attack on flat surfaces.
* Extrapolated values

TABLE 2-11

MONTHLY REMOVAL STATIC CORROSION [illegible] (NO PITTING AND MINOR CREVICE CORROSION)

TI 6AL-4V

MONTHS EXPOSED	UNWELDED SPECIMEN 1			UNWELDED SPECIMEN 2			WELDED SPECIMEN (1) 1			WELDED SPECIMEN 2			% FOULED	AVG WATER TEMP. (°F)
	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION		
[illegible]			None	0	0	None	0	0	None	0	0	None	25	47
	0		"		0	"	0	0	"	0	0	"	20-30	50
	0.1	[illegible]	"			"	0	[illegible]	"	0	0	"	10-20	57
[illegible]	0		"	[illegible]	0	"		[illegible]	"	0	0	"	40	67
[illegible]	0		"			"			"	0.1	0.1	"	20-25	74
	0		"			"			"	0	0	"	30	77
	0			[illegible]					"	0	0	"	40	71
	[illegible]		"			"		[illegible]	"	0	0	"	40	72
	0.1	[illegible]	"	[illegible]	[illegible]	"	[illegible]	0.1	"	0	0	"	25	71
			"			"	0		"	0	0	"	15	58
			"					0	"	0	0	"	5	52
[illegible]	0		"						"	0	0	"	5	43
[illegible]	0		"						"	0	0	"	0	43
14	0	[illegible]	"	0		"	[illegible]		"	0	0	"	5	47
15	0	[illegible]	"	0		"	[illegible]	0	"	0	0	"	30-40	57
[illegible]	0	[illegible]	"			"	0	0	"	0	0	"	75	64
[illegible]	0	[illegible]	"	[illegible]	[illegible]	"	0	0	"	0	0	"	50	71
[illegible]	0		"	[illegible]	[illegible]	"	0	0	"	0	0	"	75	76
CUMULATIVE TOTALS														
	[illegible]	<0.1	None	0		None	0	0	None	0.1	<0.1	None	--	
[illegible]	[illegible]	<0.1		[illegible]	<0.1	"	[illegible]	<0.1	"	0.1	<0.1	"	--	64
	[illegible]	<0.1	"	0.1	<0.1	"	0.1	<0.1	"	0.1	<0.1	"	--	61
24*	[illegible]	<0.1	"	0.2	<0.1	"	0.2	<0.1	"	0.1	<0.1	"	--	64

(1) Welded with TI 6AL-4V filler wire

* Extrapolated values

TABLE 2-12

MONTHLY REMOVAL STATIC CORROSION DATA (NO PITTING AND MINOR CREVICE CORROSION)

TI 6AL-2CB-1TA

MONTHS EXPOSED	UNWELDED SPECIMEN 1			UNWELDED SPECIMEN 2			WELDED SPECIMEN (2) 1			WELDED SPECIMEN 2			% FOULED	AVG WATER TEMP. (°F)
	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION		
1	0	0	None	0	0	None	0	0	None	0	0	None	25	47
2	0	0	"	0	0	No Pitting (1)	0	0	No Pitting (1)	0.1	0.2	No Pitting (1)	20-30	49
3	0	0	"	0	0	"	0	0	"	0	0	"	10-20	57
4	0	0	"	0	0	"	0.1	0.2	"	0	0	"	40	67
5	0	0	"	0	0		0	0	"	0	0	"	20-25	74
6	0.1	0.3	"	0	0	"	0	[illegible]	"	0	0	"	30	77
7	0	0	"	0	0	"	0	0	"	0	0	"	30	81
8	0	0	"	0	0	"	0	0	"	0	0	"	40	79
9	0	0	"	0.1	0.1	"	0	0	"	0.1	0.1	"	25	70
10	0	0	"	0	0	"	0	0	"	0	0	"	5	58
11	0	0	"	0	0	"	0	0	"	0	0	"	5	52
12	0	0	"	0	0	"	0	0	"	0	0	"	5	43
13	0	0	"	0	0	"	0	0	"	0	0	"	0	43
14	0	0	"	0	0	"	0	0	"	0	0	"	5	48
15	0	0	"	0	0	"	0	0	"	0	0	"	30-40	57
16	0	0	"	0	0	"	0	0	"	0	0	"	75	64
17	0	0	"	0	0	"	0	0	"	0	0	"	80	70
18	0	0	"	0	0	"	0.1	0.1	"	0	0	"	75	76
CUMULATIVE TOTALS														
6	0.1	<0.1	None	0	0	No Pitting(1)	0.1	<0.1	No Pitting(1)	0.1	<0.1	No Pitting(1)	--	66
12	0.1	<0.1	"	0.1	<0.1	"	0.1	<0.1	"	0.2	<0.1	"	--	64
18	0.1	<0.1	"	0.1	<0.1	"	0.2	<0.1	"	0.2	<0.1	"	--	61
24*	0.1	<0.1	"	0.2	<0.1	"	0.2	<0.1	"	0.2	<0.1	"	--	64

(1) Incipient corrosion adjacent to insulators

(2) Butt Welded without filler wire

*Extrapolated values

TABLE 2-13

MONTHLY REMOVAL STATIC CORROSION DATA (NO PITTING AND MINOR CREVICE CORROSION)
BERYLLIUM COPPER (BERYLCO 25)

MONTHS EXPOSED	UNWELDED SPECIMEN 1			UNWELDED SPECIMEN 2			WELDED SPECIMEN (2) 1			WELDED SPECIMEN 2			% FOULED	AVG WATER TEMP. (°F)
	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	MO. RATE (MPY)	CREVICE & PITTING CORROSION		
1	3.4	2.6	None	3.5	2.7	None	2.4	1.8	None	2.3	1.8	None	0	55
2	2.5	1.9	"	2.5	1.9	"	4.9	3.8	"	3.9	3.0	"	0	47
3	3.2	2.5	"	3.4	2.6	"	1.7	1.4	"	2.8	2.4	"	0	47
4	3.1	2.5	"	3.0	2.5	"	2.9	2.4	"	2.8	2.4	"	0	49
5	2.8	2.4	"	2.9	2.4	"	3.0	2.5	"	2.9	2.5	"	0	57
6	3.1	2.5	"	3.3	2.6	"	3.4	3.[illegible]	"	2.9	2.5	"	0	67
7	3.7	3.2	"	3.5	2.7	"	2.8	2.4	"	2.9	2.5	"	0	74
8	3.0	2.4	"	3.1	2.5	"	3.7	3.2	"	3.6	2.9	"	0	77
9	3.7	3.2	"	3.8	3.3	"	3.5	2.8	"	3.5	2.8	"	0	79
10	19.6	15.7	"	25.1	20.1	"	3.[illegible]	2.7	"	3.2	2.6	"	0	80
11	3.0	2.4	"	3.0	2.4	"	2.9	2.4	"	2.8	2.4	"	0	71
12	2.8	2.4	"	2.[illegible]	2.4	"	2.4	1.8	"	2.3	1.8	"	0	58
13	2.4	1.9	"	2.5	1.[illegible]	"	2.4	1.8	"	2.5	1.9	"	0	52
14	2.1	1.4	"	2.3	1.7	"	1.9	1.7	"	1.9	1.7	"	0	44
15	1.8	1.3	"	1.8	1.3	"	3.8	2.[illegible]	"	4.0	3.0	"	0	43
16	3.7	3.2	"	3.7	2.7	"	4.[illegible]	3.6	"	4.5	3.5	"	0	48
17	4.7	4.0	"	4.6	3.9	"	4.1	3.0	"	4.4	3.2	"	0	57
18	8.8	6.4	(1)	3.9	2.8	(1)	5.2	4.8	(1)	4.8	3.7	(1)	0	64
CUMULATIVE TOTALS														
6	18.4	2.4	(1)	18.6	2.4	(1)	18.3	2.4	(1)	17.6	2.3	(1)	--	54
12	53.9	2.4	"	59.9	2.4	"	[illegible]6.8	2.3	"	35.9	2.3	"	--	73
18	77.4	2.6	"	78.7	2.4	"	59.0	2.5	"	58.0	2.5	"	--	55
24*	80.9	2.6	"	76.3	2.4	"	77.5	2.5	"	76.3	2.4	"	--	73

(1) Photographs show slight crevice corrosion at points of control with insulators. (2) Welded with Berylco 25 filler wire. *Extrapolated values

TABLE 2-14

[illegible] (NO PITTING AND MINOR CREVICE CORROSION)

HASTELLOY C FOR HY [illegible] CLADDING

MONTHS EXPOSED	WELDED SPECIMEN (1) 1			WELDED SPECIMEN 2			% FOULED	AVG WATER TEMP. (°F)
	WT LOSS (GMS)	NO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	NO. RATE (MPY)	CREVICE & PITTING CORROSION		
1	0.1	<0.1	None	0.1	[illegible]	None	[illegible]	55
2	0.1	<0.1		[illegible]	<0.1		[illegible]	47
3	0	0	"	0	[illegible]	"	10	47
4	0	0	"	0	0	"	5	[illegible]
5	0	0	"	0	[illegible]	"	20-30	[illegible]
6	0.1	<0.1	"	0	0	"	[illegible]	57
7	0	0	"	0.1	<0.1	"	15-20	74
8	0	0	"	0	0	"	30-40	77
9	0.1	<0.1	"	0	0	"	40	79
10	0.1	<0.1	"	0.1	<0.1	"	[illegible]	[illegible]
11	0	0	"	0.1	<0.1	[illegible]	[illegible]	[illegible]
12	0.1	<0.1	"	0	0	"	[illegible]	[illegible]
13	0	0	"	0	0	"	[illegible]	52
14	0	0	"	0	0	"	[illegible]	44
15	0	0	"	0	0	"	[illegible]	[illegible]
16	0	0	"	0	0	"	[illegible]	[illegible]
17	0	0	"	0	0	"	30	57
18	0.1	<0.1	"	0.2	0.1	"	[illegible]	64
CUMULATIVE TOTALS								
6	0.3	<0.1	None	0.2	<0.1	None	--	
12	0.6	<0.1	"	0.5	<0.1	"	--	
18	0.7	<0.1	"	0.7	<0.1	"	--	
24*	1.0	<0.1	"	1.0	<0.1	"	--	

HASTELLOY C FOR AISI 4330M CLADDING

MONTHS EXPOSED	WELDED SPECIMEN (1) 1			WELDED SPECIMEN 2			% FOULED	AVG WATER TEMP. (°F)
	WT LOSS (GMS)	NO. RATE (MPY)	CREVICE & PITTING CORROSION	WT LOSS (GMS)	NO. RATE (MPY)	CREVICE & PITTING CORROSION		
1	0	0	None	0	0	None	25	47
2	0	0	"	0	0	"	20-30	50
3	0	0	"	0	0	"	10	57
4	0.1	<0.1	"	0	0	"	40	67
5	0	0	"	0	0	"	20	74
6	0	0	"	0	0	"	30	77
7	0.2	0.1	"	0.2	0.1	"	25	81
8	0.1	<0.1	"	0	0	"	25	79
9	0	0	"	0.1	<0.1	"	25	71
10	0	0	"	0	0	"	5	58
11	0	0	"	0	0	"	5	52
12	0	0	"	0	0	"	5	43
13	0	0	"	0	0	"	0	43
14	0	0	"	0	0	"	5	48
15	0.1	<0.1	"	0	0	"	30	57
16	0.1	<0.1	"	0.2	0.1	"	75	64
17	0	0	"	0	0	"	80	70
18	0.1	<0.1	"	0	0	"	75	76
CUMULATIVE TOTALS								
6	0.1	<0.1	None	0	0	None	--	66
12	0.4	<0.1	"	0.3	<0.1	"	--	64
18	0.7	<0.1	"	0.5	<0.1	"	--	61
24*	1.0	<0.1	"	0.8	<0.1	"	--	64

(1) Welded with Hastelloy C filler wire.

* Extrapolated values

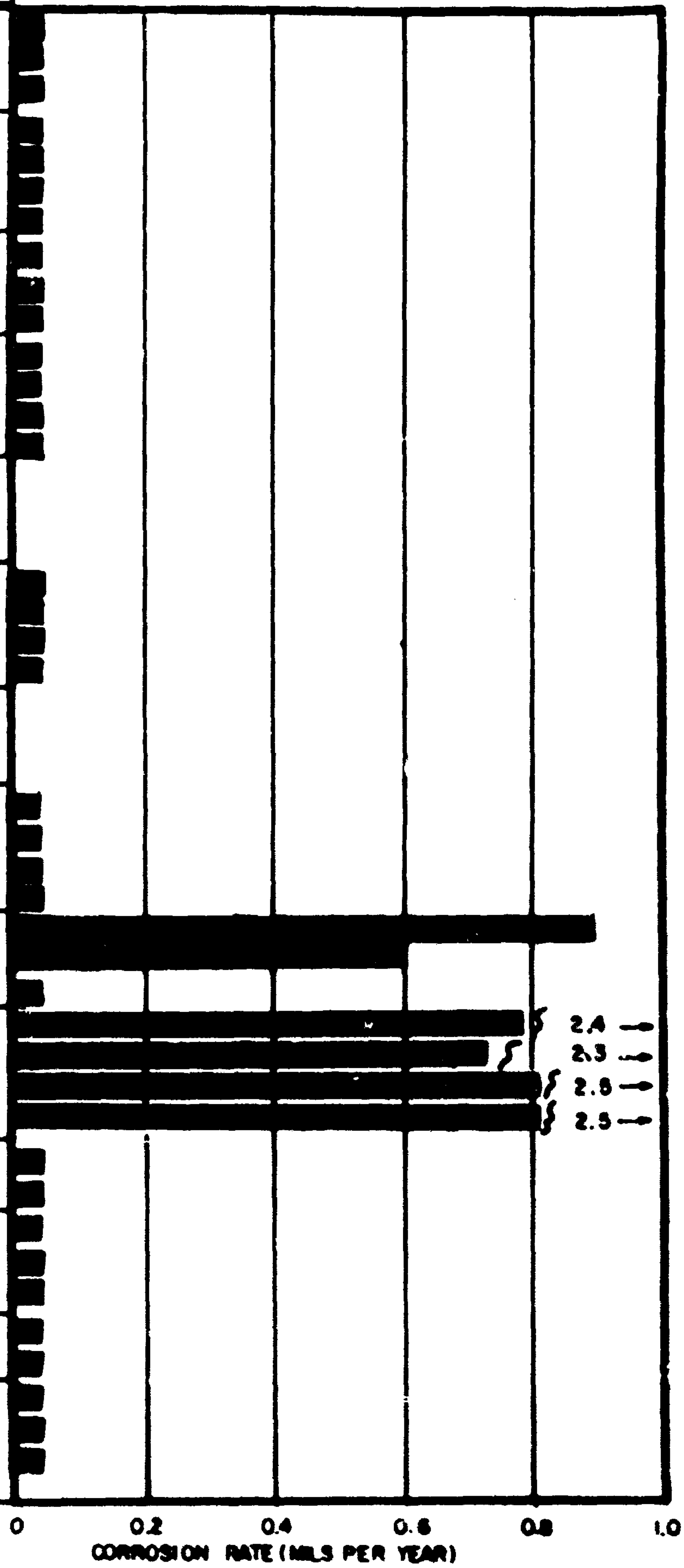
TABLE 2-15

CONTINUOUS IMMERSION [illegible] CORROSION DATA (NO PITTING AND MINOR CREVICE CORROSION)

MONTHS EXPOSED	UNWELDED SPECIMEN 1 WT LOSS (GMS)	RATE (MPY)	PITTING (MILS)	CREVICE CORROSION DEPTH (MILS)	UNWELDED SPECIMEN 2 WT LOSS (GMS)	RATE (MPY)	PITTING (MILS)	CREVICE CORROSION DEPTH (MILS)	WELDED SPECIMEN 1 WT LOSS (GMS)	RATE (MPY)	PITTING (MILS)	CREVICE CORROSION DEPTH (MILS)	WELDED SPECIMEN 2 WT LOSS (GMS)	RATE (MPY)	PITTING (MILS)	CREVICE CORROSION DEPTH (MILS)	% FOULED	AVG WATER TEMP. (°F)
INCONEL 718																		
[illegible]	[illegible]	[illegible]	None	Incipient[1]	[illegible]	<0.1	None	Incipient[2]	[illegible]	<0.1	None	None	0.3	<0.1	None	None	80	52
[illegible]	[illegible]	<0.1	None	None	[illegible]	--	Pit from crevice initiation		0.3	<0.1	None	None	10.3*	--	None	Incipient[2]	100	53
24	1.3	<0.1	None	Incipient	1.4	<0.1	None	Incipient[2]	0.3	<0.1	None	Incipient[2]	0.4	<0.1	None	Incipient[2]	100	62
INCONEL [illegible] WELDED WITH RENE' 41 FILLER WIRE																		
6				NO SPECIMENS					0.1	<0.1	None	Incipient[2]	0.5	<0.1	None	Incipient[2]	90	62
12									0	0	None		6.2*	--	None		100	63
24									0.4	<0.1	None	"	0.3	<0.1	None	"	100	62
TI [illegible]																		
[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	None	None	0	0	None	None	0	0	None	None	90	62
[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	None	None	[illegible]	[illegible]	None	None	0	0	None	None	100	63
[illegible]	0	[illegible]	None	None	[illegible]	[illegible]	None	None				NO SPECIMENS						
TI [illegible]-2CB-1T[illegible]																		
[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	None	None	[illegible]	[illegible]	None	None	0	0	None	None	90	62
[illegible]	0	[illegible]	None	None	[illegible]	[illegible]	None	None	[illegible]	[illegible]	None	None	0	0	None	None	100	63
[illegible]	[illegible]	[illegible]	None	None	[illegible]	[illegible]	None	None				NO SPECIMENS						
BERYLLIUM COPPER (BERYLCO 25)																		
[illegible]	[illegible]	[illegible]	None	Incipient[1]	[illegible]	[illegible]	None	Incipient[1]	[illegible]*	--	None	Incipient[1]	6.5	[illegible]	None	Incipient[1]	0	62
[illegible]	[illegible]	[illegible]	None	[illegible]	[illegible]	[illegible]	None		[illegible]	0.5	None	[illegible]	[illegible]	0.5	None	5, 10[1]	0	63
[illegible]	[illegible]	<0.1	None	Incipient[1]	[illegible]	<0.1	None	Incipient[1]	[illegible]	<0.1	None	Incipient[1]	11.1	<0.1	None	Incipient[1]	0	[illegible]
HASTELLOY C FOR HY [illegible] CLADDING																		
[illegible]				NO SPECIMENS					[illegible]	<0.1	None	None	[illegible]	<0.1	None	None	90	62
[illegible]									[illegible]	<0.1	None	None	0.4	<0.1	None	None	100	53
[illegible]									[illegible]	<0.1	None	Incipient[2]	0	0	None	Incipient[2]	100	62
HASTELLOY C FOR AISI 43[illegible] CLADDING																		
[illegible]				NO SPECIMENS					[illegible]	<0.1	None	None	[illegible]	<0.1	None	None	90	52
[illegible]									[illegible]	<0.1	None	None	[illegible]	<0.1	None	None	100	63
[illegible]												NO SPECIMENS						

(1) [illegible] (2) Under [illegible] *Value not considered valid.

MATERIAL AND SPECIMEN TYPE	TYPE EXPOSURE	MO. EXP.
INCONEL 718 WELDED AND UNWELDED	Continuous	6 12 24
	Removed Monthly	6 12 18 *24
INCONEL 718 WELDED WITH RENE' 41 FILLER WIRE	Continuous	6 12 24
	Removed Monthly	6 12 18 *24
TI 6AL-4V WELDED AND UNWELDED	Continuous	6 12 24
	Removed Monthly (1)	6 12 18 *24
TI 8AL-2CB-1TA WELDED AND UNWELDED	Continuous	6 12 24
	Removed Monthly (1)	6 12 18 *24
BERYLLIUM COPPER (BERYLCO 25) WELDED AND UNWELDED	Continuous	6 12 24
	Removed Monthly (1)	5 12 18 *24
HASTELLOY C FOR CLADDING ON HY 100 WELDED ONLY	Continuous	6 12
	Removed Monthly (1)	6 12 18
HASTELLOY C FOR CLADDING ON AISI 4330M WELDED ONLY	Continuous	6 12
	Removed Monthly (1)	6 12 18



*Extrapolated Value
(1) Cumulative values

FIGURE 2.1 STATIC CORROSION RATES
(NO PITTING AND MINOR CREVICE CORROSION)

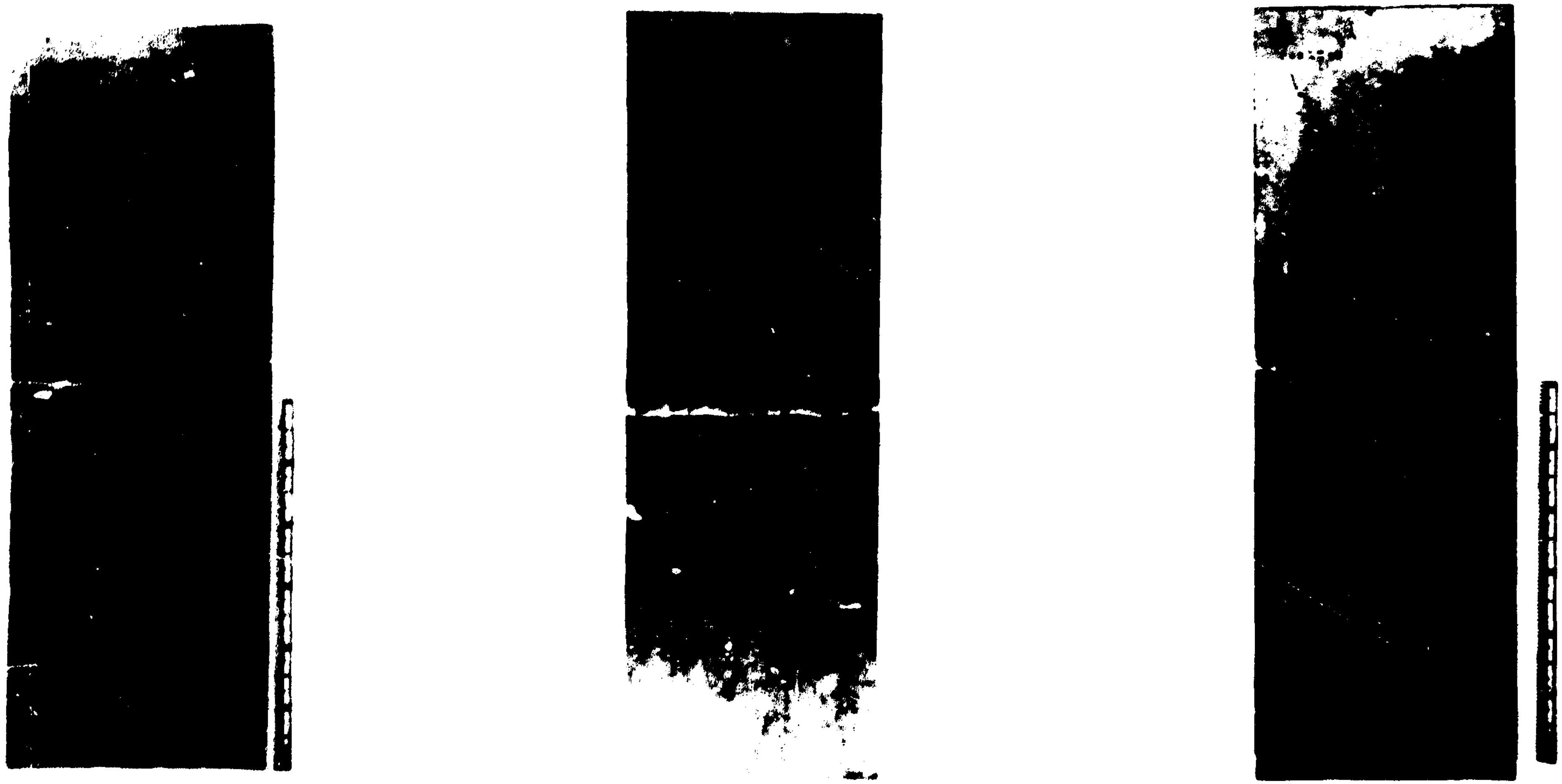
INCONEL 718
WELDED WITH INCONEL
718 FILLER WIRE
RATE - <0.1 MPY

INCONEL 718
WELDED WITH RENE 41
FILLER WIRE
RATE <0.1 MPY

TI 6AL-4V
UNWELDED
RATE = 0.0 MPY

TI 8AL-2CB-1TA
UNWELDED
RATE = 0.0 MPY

FIGURE 2.3. STATIC CORROSION SPECIMENS AFTER TWO YEARS CONTINUOUS IMMERSION IN SEA WATER.
NO PITTING AND MINOR CREVICE CORROSION.



BERYLLIUM COPPER
(BERYLCO 25)
WELDED WITH BERYLCO 25
FILLER WIRE, IMMERSED
2 YEARS

RATE - <0.1 MPY

HASTELLOY C
HY 100 HEAT TREATMENT
WELDED WITH HASTELLOY C
FILLER WIRE, IMMERSED
1 YEAR

RATE - <0.1 MPY

HASTELLOY C
AISI 4330M HEAT
TREATMENT, WELDED WITH
HASTELLOY C FILLER WIRE
IMMERSED 1 YEAR

RATE - <0.1 MPY

FIGURE 2.4. STATIC CORROSION SPECIMENS AFTER TWO YEARS CONTINUOUS IMMERSION IN SEA WATER.
NO PITTING AND MINOR CREVICE CORROSION.

TABLE 2-16
MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

K MONEL

MONTHS EXPOSED	UNWELDED SPECIMEN 1: WT. LOSS (GMS)	DEEPEST PIT (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)	UNWELDED SPECIMEN 2: WT LOSS (GMS)	DEEPEST PIT (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)	% FOULED	AVG. WATER TEMP. °F
[illegible]	[illegible]	[illegible]	[illegible]	--		[illegible]	[illegible]	3	--	6^{1}	10	55
[illegible]	[illegible]	[illegible]		--	[illegible]	[illegible]	[illegible]		--	8^{1}	0	47
[illegible]	[illegible]	[illegible]		--	[illegible]	[illegible]	10		--	12^{1}	5	47
[illegible]	[illegible]	[illegible]	[illegible]	Numerous	[illegible]	[illegible]	10		Numerous	[illegible]	30-40	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	[illegible]		--	15^{1}	20-30	57
[illegible]	[illegible]	[illegible]		(2)	[illegible]	[illegible]	[illegible]		(2)	16^{1}	20	67
[illegible]	[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	[illegible]		--	29^{1}	15	74
[illegible]	[illegible]	[illegible]		--	[illegible]	[illegible]	[illegible]		--	[illegible]	15	[illegible]
[illegible]	[illegible]	[illegible]		Craters [illegible]	[illegible]		[illegible]		Craters to [illegible]	$45^{1,2}$	25	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Craters [illegible]	[illegible]	[illegible]	[illegible]		Craters to 35	$40^{1,3}$	25	90
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	12	[illegible]	[illegible]	25	71
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Craters [illegible]	[illegible]	[illegible]	[illegible]	12	[illegible]	[illegible]	[illegible]	52
[illegible]		[illegible]		[illegible]	[illegible]			12	[illegible]	[illegible]	5	44
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	43
[illegible]		[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	5	48
[illegible]		[illegible]		Craters [illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	40-50	[illegible]
[illegible]	[illegible]	[illegible]			[illegible]		[illegible]	12	[illegible]	[illegible]	60	54
CUMULATIVE TOTALS												
[illegible]	[illegible]	[illegible]		Numerous [illegible]	15	[illegible]			Numerous to [illegible]	[illegible]	--	54
12	41.6	[illegible]		Craters [illegible]	[illegible]	42.5		[illegible]	Craters to 35	[illegible]	--	73
[illegible]	40.0	[illegible]	[illegible]	Craters [illegible]	[illegible]	40.5	[illegible]	[illegible]	Craters to 35	[illegible]	--	55
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	--	81.0	[illegible]	16	--	--	--	73

(1) Adjacent to insulators (2) Considerable increase in pitting. (3) Some crevice corrosion on all surfaces. (4) Welded with Inco No. 64 filler wire.

*Extrapolated values

TABLE 2-17
MONTHLY [illegible] STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

K MONEL

MONTHS EXPOSED	WELDED SPECIMEN[4] 1 WT LOSS (GMS)	DEEPEST PITS (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)	WELDED SPECIMEN 2 WT LOSS (GMS)	DEEPEST PITS (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)	% FOULED	AVG. WATER TEMP. °F
1	1.6	[illegible]	3	--	10[1]	4.3	3	3	--	4[1]	10	55
2	[illegible]	[illegible]	[illegible]	--	[illegible]	[illegible]	11	6	--	9[1]	0	47
3	0.1	[illegible]	[illegible]	--	[illegible]	0	11	[illegible]	--	9[1]	5	47
4	0	[illegible]	[illegible]	Numerous	[illegible]	[illegible]	11	[illegible]	Numerous	10[1]	30-40	[illegible]
5	0.2	[illegible]	[illegible]	--	20[1]	[illegible]	12	[illegible]	--	13[1]	20-30	57
6	3.7	[illegible]	[illegible]	(2)	20[1]	[illegible]	12	[illegible]	(2)	13[1]	20	67
7	4.1	[illegible]	[illegible]	--	29[1]	[illegible]	13	[illegible]	--	30[1]	15	74
8	6.0	[illegible]	[illegible]	--	[illegible]	[illegible]	13	[illegible]	--	[illegible][1,3]	15	77
9	5.7	[illegible]	[illegible]	Craters to [illegible]	[illegible]	[illegible]	15	9	Craters to 29	50[1,3]	25	[illegible]
10	6.8	[illegible]	[illegible]	Craters to [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Craters to 33	57[1,3]	25	[illegible]
11	5.8	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible]	9	"	68[1,3]	25	71
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	10	"	70[1,3]	5-10	58
13	2.0	[illegible]	[illegible]	Craters to 37	[illegible]	[illegible]	20	11	"	80[1,3]	5	52
14	0.1	17	10	"	[illegible]		20	11	"	80[1,3]	5	44
15	0	17	10	"	75[1,3]	0	20	11	"	80[1,3]	0	43
16	0	17	10	"	75[1,3]	0	20	11	"	80[1,3]	5	48
17	0	[illegible]	10	"	75[1,3]	0.1	20	11	"	80[1,3]	40-50	57
18	3.8	22	11	"	75[1,3]	4.2	20	11	"	80[1,3]	60	64
CUMULATIVE TOTALS												
6	8.2	10	8	Numerous to 1	20[1]	6.9	12	8	Numerous to 1	13[1]	--	54
12	38.4	17	10	Craters to 37	68[1,3]	39.2	20	10	Craters to 33	70[1,3]	--	73
18	44.1	22	11	Craters to 39	75[1,3]	45.6	20	11	Craters to 33	80[1,3]	--	55
24*	74.5	28	13	--	--	75.9	23	12	--	--	--	73

(1) Adjacent to insulators. (2) Considerable increase in pitting. (3) Some crevice corrosion on all surfaces. (4) Welded with Inco No. 64 filler wire.

*Extrapolated values

TABLE 2-18
MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

17-4 PH (H 1025)

MONTHS EXPOSED	UNWELDED SPECIMEN 1			UNWELDED SPECIMEN 2			% FOULED	AVG. WATER TEMP. °F
	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGE (MILS)		
1	0.9	1/4[2]	None	[illegible]	1/4[2]	None	10	55
2	0.2	1 1/[illegible] x 1/4 x 195[2]	"	0.2	1 1/[illegible] x 1/4 x 180[2]	"	20	47
3	0	1 1/[illegible] x 1/4 x 20[illegible]	"	[illegible]	1 1/[illegible] x 1/4 x 180[2]	"	30	47
4	0	"	[illegible]	[illegible]	"	"	30-40	49
5	0	206[2]	[illegible]		"	"	20-30	57
6	0.7	208[2]	115, 11[illegible]	1.2	190[2]	180[2]	40	67
7	1.4	210[2]	109, 103, 112, [illegible]	1.1	195[2]	180, 125[2], 83[3]	20	74
8	2.2	312[2]	6 - 92 to 312[2]	2.7	232[2]	7 - 85 to 232[2,3]	30-40	77
9	3.5	5/16 x 1 Perf.*[2]	4 - 202[2]	3.[illegible]	1 5/[illegible] x 5/16 x [illegible]50[2]	180[2], 85[3]	40	79
10	5.2	Perforation [2]	Numerous to [illegible]	[illegible]	Perforation [2]	Numerous to 325[2,3]	40	80
11	4.[illegible]	Perforation [illegible]	Numerous Pits & Perforations[illegible]	[illegible]	Perforation [2]	Numerous[2,3]	25	71
12	[illegible]	Perforation [2]	"	[illegible]	Perforation [2,3]	Numerous Pits & Perforations[2,3]	5-10	59
13	[illegible]	Perforation [2]	"	[illegible]	Perforation [2,3]	"	5	52
14	[illegible]	Perforation [2]	"	[illegible]	Perforation [2,3]	"	5	44
15	[illegible]	"	"	0	[illegible]	"	0	43
16	0	"	"			"	5	42
17	0	"	"	[illegible]		"	40-50	57
18	[illegible]	"		[illegible]		"	75	64
CUMULATIVE TOTALS								
6	[illegible]	20[illegible][2]	———	[illegible]	190[2]	———	--	54
12	20.2	Perforation [2]	———	20.1	Perforation [2,3]	———	--	73
18	22.8	Perforation [2]	———	22.5	Perforation [2,3]	———	--	55
24**	41.2	Perforation [2]	———	40.0	Perforation [2,3]	———	--	73

(1) Welded with Arcos No. 527 Chromenar filler wire. (2) Edge (3) Surface (4) Weld (5) HAZ *Perforation(s) **Extrapolated values

TABLE 2-19

MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

[illegible]-4 PH ([illegible])

MONTHS EXPOSED	WELDED SPECIMEN 1 WT LOSS (GMS)	WELDED SPECIMEN 1 DEEPEST PIT (MILS OR IN)	WELDED SPECIMEN 1 PITS NOT AVERAGED (MILS)	WELDED SPECIMEN[1] 2 WT LOSS (GMS)	WELDED SPECIMEN[1] 2 DEEPEST PIT (MILS OR IN)	WELDED SPECIMEN[1] 2 PITS NOT AVERAGED (MILS)	% FOULED	AVG. WATER TEMP. °F
1	0.3	[illegible]	None	[illegible]	2 [illegible]	None	10	55
2	0.3	[illegible]	[illegible], 45[2], [illegible]	[illegible]	[illegible] x 3/16 x 155[2]	1/16D x 75,[4] 1/16D x 115[2], 1/32D x 37, 3/16D x [illegible]	20	[illegible]
3	0	[illegible]	[illegible] D x [illegible]	[illegible]	3/16 x 3/16 x 160[2]	1/16 x 75, 1/16 x 115,[2], 1/32 x 40, 3/16 x 130[4]	30	47
4	0	"	56, 47[2]	0	"	78, 40, 130[4], 115[2]	30-40	49
5	0.1	"	56, 50[2]	0.1	"	78, 40, 130[4], 115[2]	20-30	57
6	[illegible]	[illegible]	56, 155[2]	.1	Perforation(s)[5]*	78, 40, 115, 150[2], 115[4]	40	67
7	1.3	[illegible]	[illegible] 190, 60, [illegible]	[illegible]	1/2 Perf.[5]	3 - 160[2], 63[3], 130[4]	20	74
8	2.[illegible]	2[illegible]	[illegible]-34 to 235[2,3]	2.5	13/16 Perf.[5]	3-160[2], 130[4], 120[3]	30-40	77
9	3.4	1/[illegible] x 5/[illegible] Perf.[5]	11 - 235[2,3]	[illegible].2	1 1/4 Perf.[5]	5 - 155[2,3]	40	79
10	4.[illegible]	[illegible] Perf.[5]	Numerous to 2[illegible]	4.5	1 1/2 Perf.[5]	Numerous to 156[2,3]	40	80
11	4.[illegible]	[illegible] Perf.[5]	1/4 x 1/2 Perf ... Numerous to 230[2,3]	[illegible]	1 [illegible] Perf.[5]	Numerous to 230[2,3]	25	71
12	1.6	1/8 x 1 1/4 Perf.[5]	Numerous Pits + [illegible] Perf.[illegible]	1.6	2 1/4 Perf.[5]	Numerous Pits & Perforations[2,3]	[illegible]-10	58
13	1.6	1/8 x 1 1/2 Perf.[5]	"	1.2	1/8 x 2 5/16 Perf.[5]	"	5	52
14	0	"	"	0.1	"	"	5	44
15	0	"	"	0	"	"	0	43
16	0	"	"	0	"	"	5	48
17	0	"	"	0	"	"	40-50	57
18	1.2	"	"	1.7	1/8 x 2 5/8 Perf.[5]	"	75	64
CUMULATIVE TOTALS								
6	1.8	20[2]	———	3.4	Perf.[5]	———	--	54
12	20.3	1/8 x 1 1/4 Perf.[5]	———	22.1	2 1/8 Perf.[5]	———	--	73
18	27.5	1/8 x 1 1/2 Perf.[5]	———	25.1	1/8 x 2 5/8 Perf.[5]	———	--	55
24**	40.0	Perf.[5]	———	43.8	Perf.[5]	———	--	73

(1) Welded with Arcos No. 327 Chromener Filler wire. (2) Edge (3) Surface (4) Weld (5) HAZ *Perforation(s) **Extrapolated values

TABLE 2-20
MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

17-4 PH (H 1075)

MONTHS EXPOSED	UNWELDED SPECIMEN 1			UNWELDED SPECIMEN 2			% FOULED	AVG. WATER TEMP. °F
	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)		
1	1.0	3/16[1]	None	1.1	5/16[1]	None	10	55
2	0.1	1/8 x 5/16 x 175[1]	2-18, 2-1/16D x 69[1]	0.3	3/16 x 1/4 x 127[1]	1/16D x 100[1]	10	47
3	0	5/16 x 5/32 x 130[1]	18, 20, 2 1/16D x 69[1]	0	"	"	25	47
4	0	"	18, 20, 2-69[1]	0.1	120[1]	100[1]	30-40	49
5	0	1[illegible]3[1]	21, 22, 70, 71[1]	0	12[illegible][1]	102[1]	20-30	57
6	0.4	"	22, 150, 70, 71[1]	0.9	21[illegible][1]	90, 149[1]	40	67
7	0.6	"	2-180, 1-120, [illegible]	[illegible].7	23[illegible][1]	2-233, 72, 148[1]	20-25	74
8	3.0	283[1]	12-70 to 2[illegible][1]	2.5	"	6 - 210[1], 5/16D x 155	30	77
9	2.6	324[1]	[illegible] - 324[1]	2.9	240[1]	5 - 240[1], 3/8D x 155[3]	40	79
10	5.2		Numerous to 23[illegible][1]	4.9	"	Numerous to 23[illegible][1,3]	40	80
11	5.4	"	"	4.7		"	25	71
12	1.8	Several Perf.[1,3]*	Severe[1]	[illegible]	Several Perf.[1,3]	Severe[1]	5-10	58
13	1.5	"	"	[illegible]	"	"	5	52
14	C	"	"	0	"	"	0	44
15	0.3	"	"	0.2	"	"	0	43
16	0	"	"	0	"	"	5	48
17	0	"	"	0	"	"	40-50	57
18	1.8	"	"	0.9	"	"	75	64
CUMULATIVE TOTALS								
6	1.5	183[1]	———	2.4	21[illegible][1]	———	--	54
12	20.1	Several Perf.[1,3]	———	19.8	Several Perf.[1,3]	———	--	73
18	23.4	Several Perf.[1,3]	———	22.6	Several Perf.[1,3]	———	--	55
24**	42.3	Several Perf.[1,3]	———	40.0	Several Perf.[1,3]	———	--	73

(1) Edge (2) HAZ (3) Surface (4) At contact with insulator (5) Incipient corrosion at contact with insulators (6) Welded with Arcos No. 327 Chromenar filler wire

*Perforation(s) **Extrapolated values

TABLE 2-21
MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

17-4 PH (H 1075)

MONTHS EXPOSED	WELDED SPECIMEN[6] 1			WELDED SPECIMEN 2			% FOULED	AVG. WATER TEMP. °F
	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)		
1	1.4	Perf.*[2]	None	2.4	5/16[1]	None	10	55
2	0.3	1/16 x 5/16 Perf.[2]	"	0.4	80[1]	10[3]	10	47
3	0	"	Crevice Corrosion 1/16D x 90[4]	0.1	1/16 x 80[1]	1/16 x 1 1/8 x 50[1]	25	47
4	0.3	"	Crevice Corrosion 94[4]	0	"	1/16 x 1 1/8 x 60[1]	30-40	49
5	0	"	Crevice Corrosion 96[4]	0	"	"	20-30	57
6	1.6	1/16 x 5/8 Perf.[2]	66, 92[1]	0.9	1/16 x 13/16 Perf.[1]	170	40	67
7	2.0	3/32 x 7/8 Perf.[2]	82, 95, 96[1]	1.0	"	3 - 72, 170[1]	20-25	74
8	3.4	1 3/16 Perf.[2]	9/16 Perf.[2], 3 95[1]	2.[illegible]	"	4 - 130[1], 210[3]	30	77
9	4.6	1/8 x 1 9/16 Perf.[2]	1/8 x 13/16 Perf[2], 3- [illegible]	3.6	"	"	40	79
10	5.8	"	1 1/4 Perf.[2], Numerous to 92[1]	3.5	"	7/8 Perf.[2], 1 1/8 Perf.[1], Numerous to 182[1]	40	80
11	4.[illegible]	3 1/2 Perf.[2]	6 - [illegible]5	7.5	1/16 x 1 1/2 Perf.[2]	5/8 Perf.[2], Severe	25	71
12	TERMINATED AFTER 11 MONTHS			1.[illegible]	"	13/16 Perf.[2], 1 1/8 Perf.[1]	5-10	58
13				1.7	1/2 x 1 3/4 Perf.[2]	1/8 x 1 3/16, Perf.[2], 2 Perf.[1]	5	52
14				0	"	"	0	44
15				0.2	"	"	0	43
16				0	"	"	5	48
17				0	"	"	40-50	57
18				1.0	1/8 x 2 1/8 Perf.[2]	"	75	64
CUMULATIVE TOTALS								
6	3.6	1/16 x 5/8 Perf.[2]	——	3.6	1/16 x 13/16 Perf.[1]	——	--	54
12	28.3	Terminated	——	23.8	1/16 x 1 1/2 Perf.[2]	——	--	73
18	——	——	——	26.7	1/8 x 2 1/8 Perf.[2]	——	--	55
24**	——	——	——	46.9	Perf.[2]	——	--	73

(1) Edge (2) HAZ (3) Surface (4) At contact with insulator (5) Incipient corrosion at contact with insulators (6) Welded with Arcos No. 327 Chromenar filler wire

*Perforation(s) **Extrapolated values

TABLE 2-22
MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

AM 355 (CAST)

MONTHS EXPOSED	UNWELDED SPECIMEN 1			UNWELDED SPECIMEN 2			% FOULED	AVG. WATER TEMP. °F
	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)		
1	0.5	(1)	None	0.6	(1)	None	25	49
2	0.6	"	"	1.4	20	3-3	10	57
3	1.9	"	"	3.2	20	3-3	40	67
4	2.3	102	5 - 102, 2 - 98	3.6	[illegible]	13 - 128, 12 - 174, 10 - 177	25	74
5	3.9	10[illegible]	[illegible] - 102, [illegible] - 10[illegible]	4.4	1[illegible]0	19 - 153, 14 - 180, [illegible] - 92	30	77
6	5.6	17[illegible]	Numerous to 1[illegible]	[illegible]	Perf.*	Numerous	25	79
7	7.2	20[illegible]	Numerous to 20[illegible]	[illegible]	Perf.	Numerous	40	80
8	6.2	23[illegible]	Numerous to [illegible]	[illegible]	Perf.	Numerous	15	71
9	4.9	Perf.*	Several Perf.	2.[illegible]	Perf.	Several Perf.	5-10	58
10	2.[illegible]	Perf.	Several Perf.	[illegible].1	Perf.	Several Perf.	5	52
11	0.[illegible]		"	[illegible]	"	"	5	44
12	[illegible]		"	1.2	"	"	0	43
13	[illegible]	"		0	"	"	5	48
14	[illegible]			0.[illegible]	"	"	35	57
15	[illegible]	"		[illegible]	"	"	75	64
[illegible]	[illegible]		"	[illegible]	"	"	80	70
[illegible]	[illegible]	"		[illegible].4	"	"	75	76
	[illegible]	"		5.0	"	"	75	79
CUMULATIVE TOTALS								
[illegible]	[illegible]	[illegible]		[illegible]	Perf.		--	69
12	37.0	Perf.		39.[illegible]	Perf.		--	58
1[illegible]	53.5	Perf.		53.[illegible]	Perf.		--	66
24**	75.7	Perf.		73.[illegible]	Perf.		--	58

( ) Incipient (2) Incipient at Simulator (3) In weld (4) Edge ( ) Welded with AM 355 filler wire *Perforation(s) **Extrapolated values

TABLE 2-23
MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

AM 355 (CAST)

MONTHS EXPOSED	WELDED SPECIMEN[5] 1			WELDED SPECIMEN 2			% FOULED	AVG. WATER TEMP. °F
	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)	WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)		
1	0.8	(1)	4-3	0.[illegible]	(1)	None	25	49
2	1.[illegible]	3/1[illegible] x [illegible] x 125	1-3/1[illegible] x 3/[illegible] x 1[illegible], 1-1/8 x 1[illegible] x 125	1.[illegible]	[illegible] x 5 1/16 x 130[3]	"	10	57
3	3.[illegible]	170[4]	1-140, 21-1[illegible] [illegible]	[illegible]	Perf.*, [illegible] x 5/8[3]	"	40	67
4	5.2	170[4]	5 - 170, 21 - [illegible]	[illegible]	Perf. [illegible]/16 x 1 [illegible]/4[3]	"	25	74
5	[illegible]	170[4]	26 - 170	[illegible]	Perf. [illegible] x 1 5/16[3]	"	30	77
6	1[illegible].0	170[4]	Numerous [illegible]	[illegible]	Perf. [illegible] x 1 [illegible]/8[3]	(1)	25	79
7	9.5	170[4]	Numerous to [illegible]	1[illegible]	Perf. [illegible] x 2[3]	78, 110	40	80
8	10.7	[illegible][4]	Numerous [illegible]	1[illegible].5	Perf. [illegible] x [illegible][3]	7[illegible], 110	15	71
9	6.[illegible]	25[illegible][4]	Numerous to 25[illegible]	1[illegible]	Perf. [illegible] 1/[illegible] x 2 1/8[3]	78, 120	5-10	58
10	5.[illegible]	25[illegible][4]	Numerous to 25[illegible]	4.	Perf. 1 1/[illegible] x 2 1/8[3]	1-1/2D x 125	5	52
11	1.[illegible]	"	"	3.0	"	"	5	44
12	1.5	"	"	1.2		"	0	43
13	1.2	"	"	0.8	"	1-1/2D x 175	5	48
14	4.8	"	"	1.0	"	1-1/2D x 175	35	57
15	7.7	"	"	5.8	"	1-142, 1-1[illegible]2, 1-[illegible]3	75	64
16	6.4	"	"	5.[illegible]	"	1-83, 1-166, 1-182	80	70
17	11.3	"		11.5	Perf. 1 3/4 x 2 3/4[3]	Perforated	75	76
18	10.5	"	"	10.[illegible]	"	"	75	79
CUMULATIVE TOTALS								
6	30.1	170[4]	————	28.4	Perf.[3]	————	--	[illegible]2
12	65.5	25[illegible][4]	————	89.5	Perf.[3]	————	--	58
18	107.4	25[illegible][4]	————	125.2	Perf.[3]	————	--	66
24**	148.8	————	————	186.3	Perf.[3]	————	--	58

(1) Incipient (2) Incipient at insulator (3) In weld (4) Edge (5) Welded with AM 355 filler wire *Perforation(s) **Extrapolated values

TABLE 2-24

MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

CD - MCU (CAST)

MONTHS EXPOSED	UNWELDED SPECIMENS 1 WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)	UNWELDED SPECIMENS 2 WT LOSS (GMS)	DEEPEST PIT (MILS OR IN)	PITS NOT AVERAGED (MILS)	% FOULED	AVG. WATER TEMP. °F
[illegible]	0.2	None	None	[illegible]	None	None	5	49
[illegible]	0	"	"	[illegible]	"	"	25	57
[illegible]	0	"	"	[illegible]	"	"	40	6[illegible]
[illegible]	[illegible]	"	"	[illegible]	"	"	25	74
[illegible]	[illegible]	"	"	0	"	"	30	[illegible]
[illegible]	0.5	"	(1) - Crevice Corrosion (2)	[illegible]	"	( )	50	79
[illegible]	[illegible]	46	( )( ) - Crevice Corrosion (2)	[illegible]	"	( )	25	[illegible]
	[illegible]	15[illegible]	[illegible], 13, [illegible] - CC	[illegible]	132	Numerous - 10 avg.	15	71
[illegible]	0.3	Perf.**	Numerous to [illegible] - CC	[illegible]	132	Numerous to 130	5	5[illegible]
[illegible]	0.4	Perf.	Numerous to [illegible] - CC	[illegible]	134	Numerous to 134	[illegible]	52
[illegible]	0	Perf.	[illegible] - CC	[illegible]	[illegible]	Numerous to 134	[illegible]	44
[illegible]	0	Perf.	[illegible] - CC	[illegible]	134	Numerous to 134	0	43
[illegible]	[illegible]	Perf.	[illegible] - CC	[illegible]	[illegible]	Numerous to 134	[illegible]	4[illegible]
[illegible]	[illegible]	"			"	"	20	57
15	0.1	"	Numerous [illegible] - CC	[illegible]	"	"	[illegible]	[illegible]
[illegible]	[illegible]	"	Numerous [illegible] - CC			"	[illegible]	70
17	[illegible]			[illegible]	[illegible]	Numerous to 135	[illegible]	[illegible]
[illegible]	[illegible]	[illegible] - Perf.		[illegible]	[illegible]	Numerous to 13[illegible]	[illegible]	[illegible]
CUMULATIVE TOTALS								
[illegible]	[illegible]	None	CC (1)	[illegible]	None	——	--	69
[illegible]	6.5	Perf.	CC - [illegible]	3.7	134	——	--	5[illegible]
[illegible]	9.0	Perf.	[illegible]	5.3	13[illegible]	——	-	66
[illegible]**	14.8	Perf.	——	7.7	——	——	--	58

(1) Incipient (2) Incipient at insulators (3) [illegible] (4) At weld (5) At Crack (6) Reverse butt welded without filler wire

*Perforation(s) **Extrapolated values

TABLE 2-25
MONTHLY REMOVAL STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

CD + MCU (CAST)

MONTHS EXPOSED	WELDED SPECIMENS (6) 1: WT LOSS (GMS)	WELDED SPECIMENS (6) 1: DEEPEST PIT (MILS OR IN)	WELDED SPECIMENS (6) 1: PITS NOT AVERAGED (MILS)	WELDED SPECIMENS 2: WT LOSS (GMS)	WELDED SPECIMENS 2: DEEPEST PIT (MILS OR IN)	WELDED SPECIMENS 2: PITS NOT AVERAGED (MILS)	% FOULED	AVG. WATER TEMP. °F
1	0	None	None	0.2	None	None	5	49
2	0	"	"	0	"	"	25	57
3	0	"	"	0	"	"	40	67
4	0	"	"	0	"	"	25	74
5	0	"	"	0	"	"	30	77
6	0.3	"	"	0	"	"	50	79
7	1.0	74	"	[illegible]	"	(1) (4)	25	80
8	1.8	1/8D Perf.	1[illegible], 30, [illegible] [3,4]	[illegible]	0	45[4] (3)	15	71
9	0.7	2 Perf.	"	0.2	147[4]	"	5	58
10	0.2	2 Perf.[5]	"	[illegible]	2 - 147[4]	"	5	52
11	0	2-1/4D Perf.[5]	"	0	2-147[4]	"	5	44
12	0	2-1/4D Perf.[5]	"	0	2-147[4]	"	0	43
13	0	2-1/2D Perf.[5]	"	[illegible]	2-147[4]	"	5	4[illegible]
14	0	"	"	0	"	"	20	57
15	0.3	"	"	0.2	"	Numerous to 115	75	64
16	0.3	"	"	0.2	"	"	75	70
17	0.1	"	Numerous to 75	0.2	"	Numerous to 152	75	76
18	1.9	"	"	3.1	"	"	75	[illegible]
CUMULATIVE TOTALS								
6	0.3	None	———	0.2	None	———	--	69
12	4.0	Perf.[5]	———	2.5	2-147[4]	———	--	58
18	6.6	Perf.[5]	———	6.2	2-147[4]	———	--	66
24**	10.3	Perf.[5]	———	8.5	———	———	--	58

(1) Incipient (2) Incipient at insulators (3) Panel cracked (4) At weld (5) At crack (6) Reverse butt welded without filler wire

*Perforation(s) **Extrapolated values

TABLE 2-26
CONTINUOUS [illegible] CORROSION DATA (PITTING AND CREVICE CORROSION)

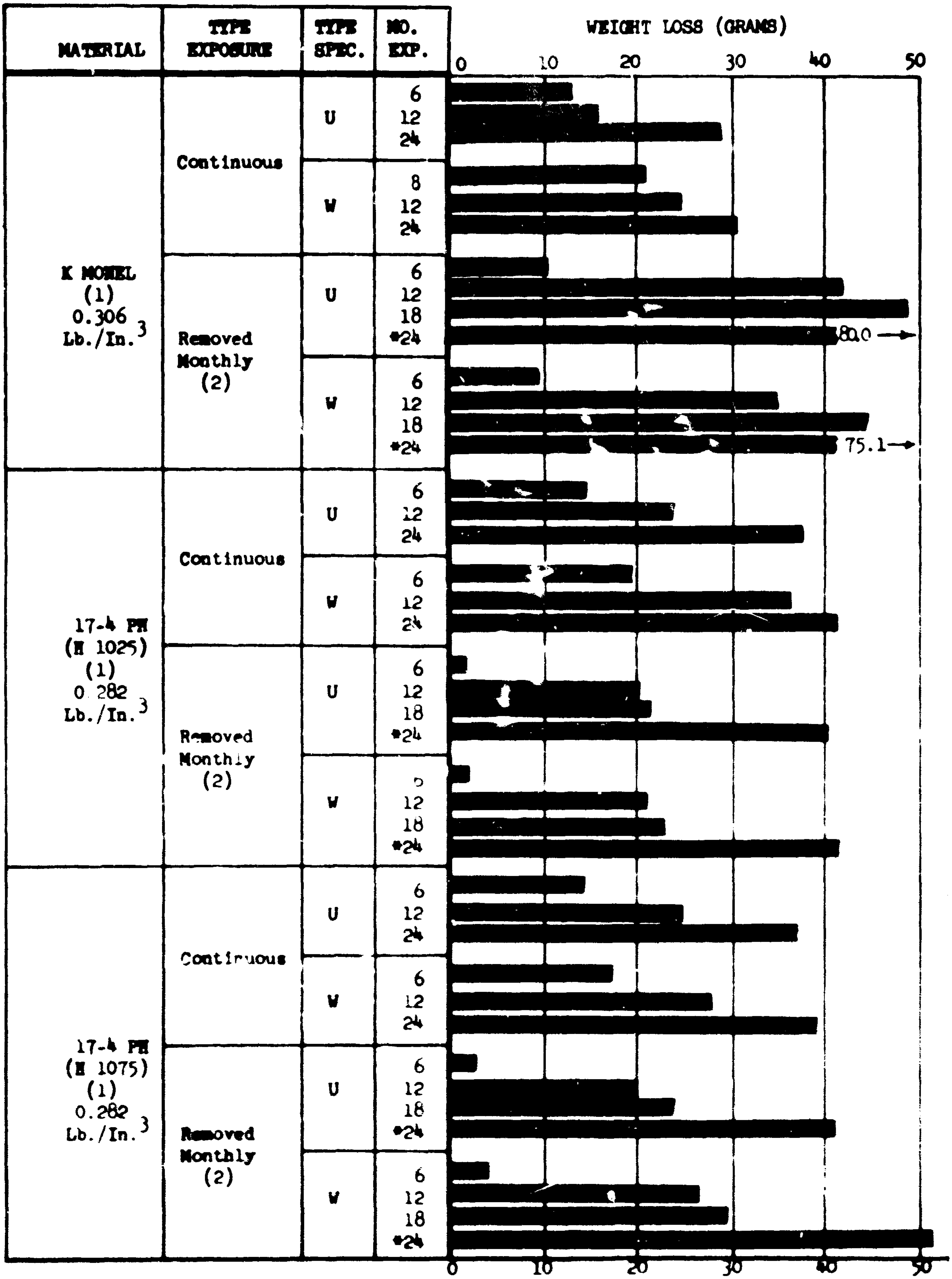
MONTHS EXPOSED	UNWELDED SPECIMEN 1					UNWELDED SPECIMEN 2					% FOULED	AVG. WATER TEMP. °F
	WT LOSS (GMS)	DEEPEST PIT (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)	WT LOSS (GMS)	DEEPEST PIT (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)		
K MONEL												
6	[illegible]	[illegible]		(2)	[illegible]	[illegible]	[illegible]	11	(2)	2 1	50	62
12	15.1	[illegible]	[illegible]	Craters to [illegible]	[illegible]	[illegible]		[illegible]	Craters to 30	2.0 1	35	63
24	[illegible]	(2)	[illegible]	Craters [illegible]	( )	[illegible]	( )	[illegible]	Craters to 42	( )	10	52
PH (H [illegible])												
6	[illegible]	[illegible] Perf.*	( )		[illegible]	[illegible]	[illegible] Perf.*	(2)	( )	None	0	[illegible]
12	[illegible]	Perf.	(2)		[illegible]	[illegible]	[illegible]	( )	(2)	Incipient	100	[illegible]
24	[illegible]	Perf.	(2)		( )	[illegible]	[illegible] Perf.	(2)	(2)	(4)	100	52
[illegible] PH (H [illegible])												
6	[illegible]	Perf.	[illegible]	(2)	[illegible]	[illegible]	[illegible]	( )	(2)	Incipient	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	(2)		[illegible]	[illegible] Perf.	( )	(2)		100	63
24	[illegible]	Perf.	(2)	(2)	( )		[illegible]	(2)	(2)	( )	100	[illegible]
[illegible] ([illegible])												
6	[illegible]	[illegible]	( )	[illegible]	( )	[illegible]	[illegible]	( )	[illegible]	( )	10	[illegible]
[illegible]	[illegible]		[illegible]	(2)			[illegible] Perf.	( )		None	100	62
24	NO SPECIMENS					NO SPECIMENS						
CD [illegible] (CAST)												
6	[illegible]	( )	( )	[illegible]	[illegible]	[illegible]	( )	( )	[illegible] Max	None	[illegible]	[illegible]
12	[illegible]	[illegible]	(2)	(2)	[illegible]	[illegible]	( )	(2)	[illegible]	None	100	[illegible]
24	NO SPECIMENS					NO SPECIMENS						

(1) [illegible] (2) [illegible] (3) [illegible] (4) [illegible] ( ) [illegible] ( ) Pine cracked ( ) [illegible] *Perforation(s)

TABLE 2-27
CONTINUOUS IMMERSION STATIC CORROSION DATA (PITTING AND CREVICE CORROSION)

MONTHS EXPOSED	WELDED SPECIMEN 1					WELDED SPECIMEN 2					% FOULED	AVG. WATER TEMP. °F
	WT LOSS (GMS)	DEEPEST PIT (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)	WT LOSS (GMS)	DEEPEST PIT (MILS)	AVG. TEN DEEPEST PITS (MILS)	PITS NOT AVERAGED (MILS)	CREVICE CORROSION DEPTH (MILS)		
[illegible]												
[illegible]	[illegible]			(2)		[illegible]	[illegible]	1	(2)	40	50	[illegible]
12	[illegible]		[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	25	[illegible]
24	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	( )	[illegible]	[illegible]	( )	0	62
[illegible]												
[illegible]	[illegible]	[illegible]*	[illegible]	(2)	[illegible]	[illegible]	[illegible]*	( )	Perf.	None	[illegible]	[illegible]
12	[illegible]	Perf.*	(2)	(2)	[illegible]	[illegible]	[illegible]	[illegible]	Perf.	Incipient[7]	100	[illegible]
24	[illegible]	Perf.	(2)	Perf.	[illegible]	[illegible]	[illegible]	(2)	Perf.	(5)	100	62
[illegible]												
[illegible]	[illegible]	Perf.	[illegible]	[illegible]	Incipient[4]	[illegible]	Perf.	[illegible]	(2)	Incipient[4]	[illegible]	62
12	24.6	Perf.	(2)	[illegible]		[illegible]	Perf.	[illegible]	(2)	[illegible]	100	63
24	[illegible]	Perf.	(2)	(2)	[illegible]	[illegible]	Perf.	(2)	(2)	[illegible]	100	62
[illegible] (CAST)												
6	[illegible]	[illegible]		(2)	Severe	[illegible]	[illegible]	[illegible]	(2)	(2)	90	69
12	[illegible]	Perf.	(2)	(2)	None	14.7	Perf.	(2)	(2)	None	100	62
24	NO SPECIMEN					NO SPECIMEN						
CD 4 MCU (CAST)												
6	1.3	(6)	(2)	Incipient	(2)	[illegible]	(6)	(2)	Incipient	(2)	90	69
12	[illegible]	(6)	(2)	[illegible]	Incipient[4]	[illegible]	(6)	(2)	[illegible]	Incipient[4]	100	62
24	NO SPECIMEN					NO SPECIMEN						

(1) At insulators (2) Not reported (3) In HAZ (4) Under Fouling (5) At corner (6) Panel cracked (7) In weld *Perforation(s)



*Extrapolated Value
(1) Density
(2) Cumulative values

FIGURE 2.2 Static Corrosion Weight Losses for Materials with Pitting and Crevice Corrosion

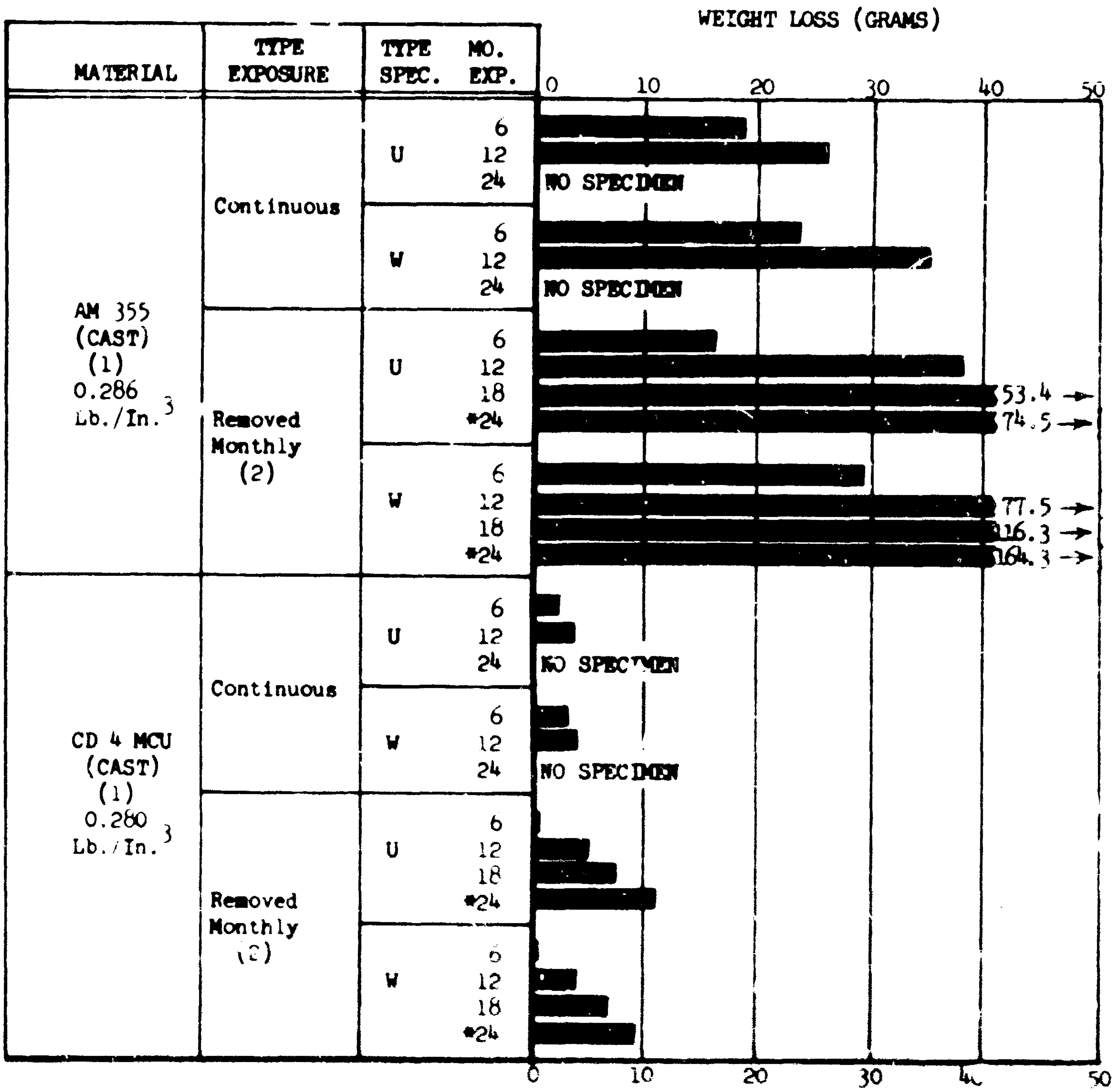
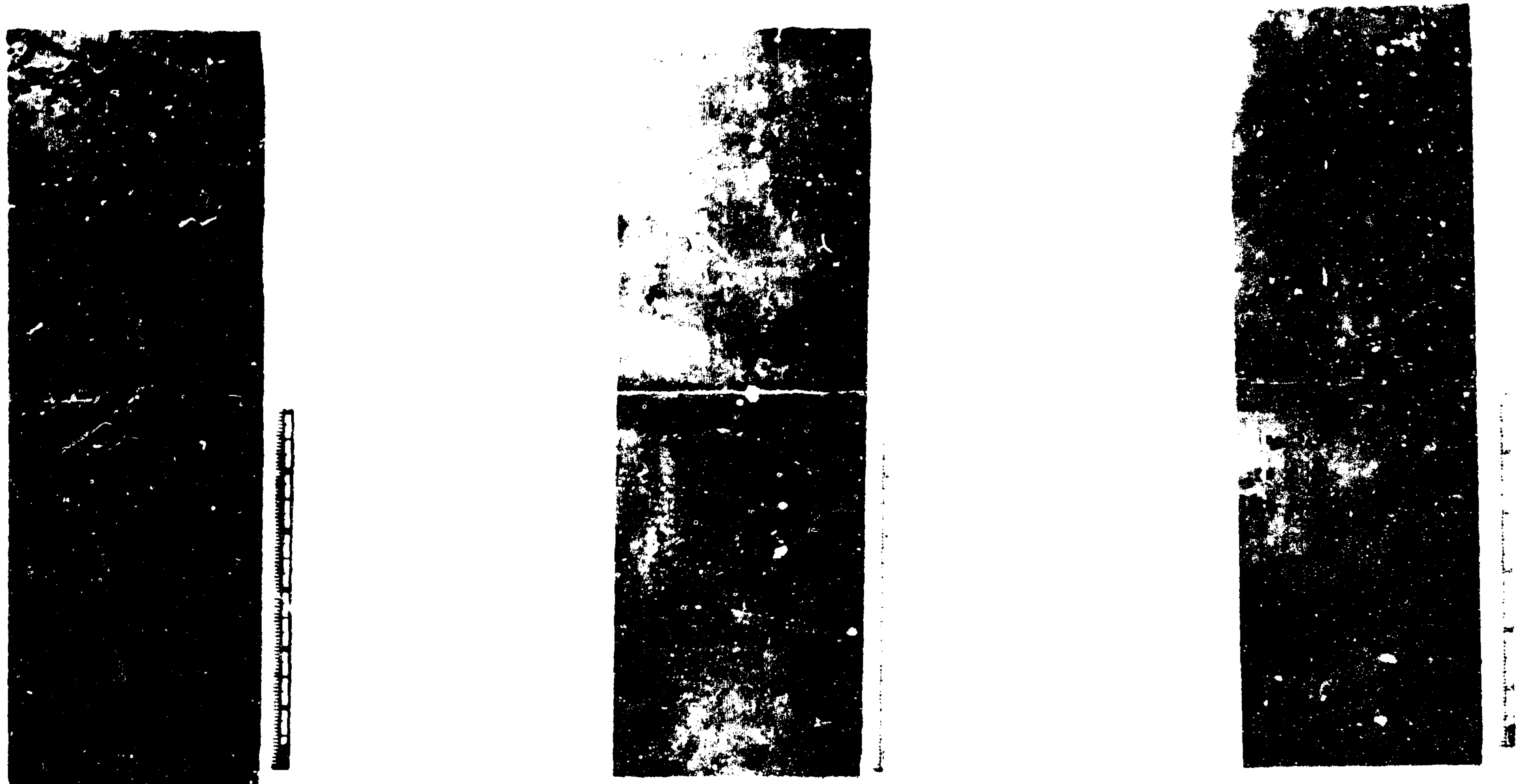


FIGURE [illegible] (Continued)

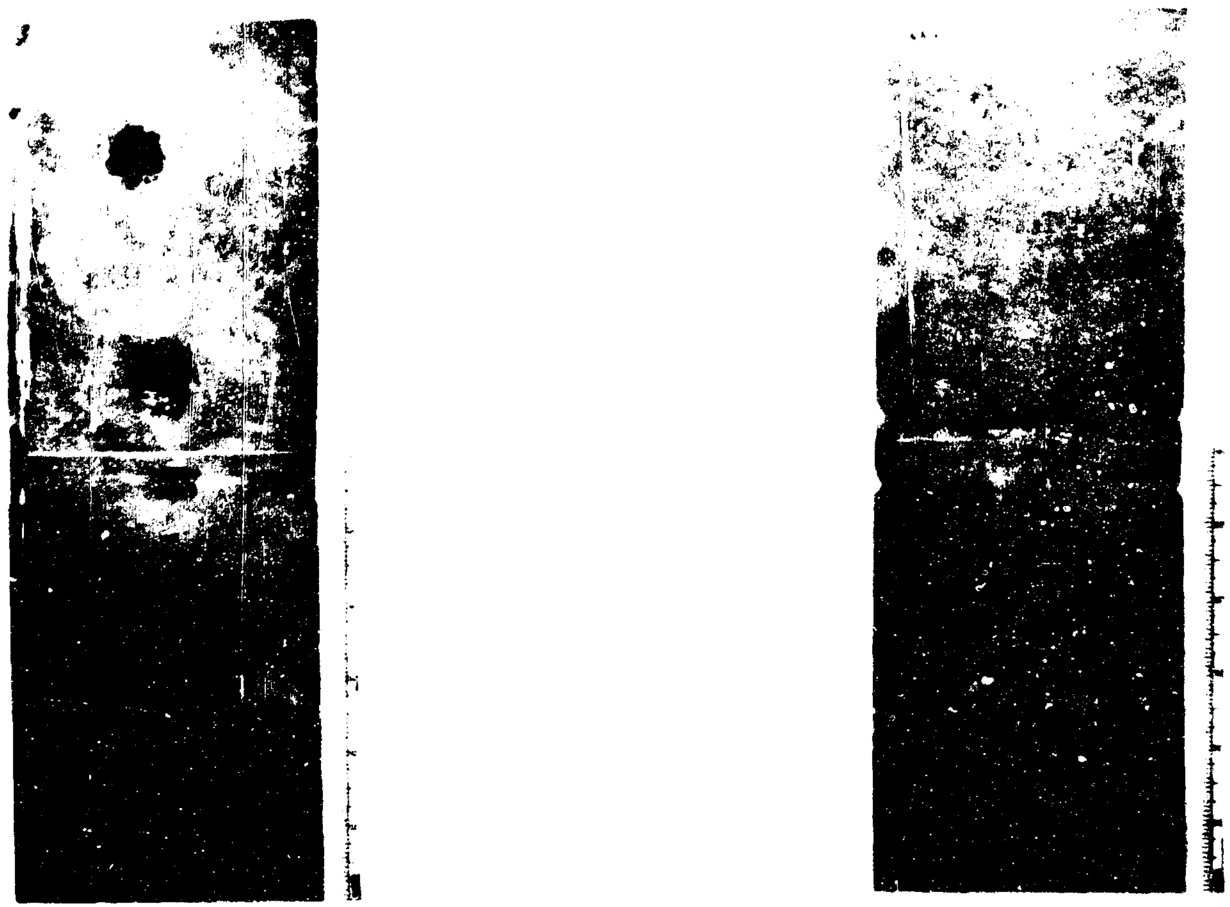


K MONEL
WT. LOSS - 30.[illegible] GRAMS

17-4PH (H 1025)
WT. LOSS - 41.0 GRAMS

17-4PH (H 1075)
WT. LOSS - 39.1 GRAMS

FIGURE 2.5. WELDED STATIC CORROSION SPECIMENS AFTER TWO YEARS CONTINUOUS IMMERSION IN SEA WATER, SHOWING PITTING AND CREVICE CORROSION.



AM 355 (CAST)
WT. LOSS - 34.8 GRAMS

CD 4 MCU (CAST)
WT. LOSS - 4.1 GRAMS

FIGURE 2.6. WELDED STATIC CORROSION SPECIMENS AFTER ONE YEAR CONTINUOUS IMMERSION IN SEA WATER SHOWING PITTING AND CRACKING.

2.6 STRESS CORROSION

2.6.1 Bent beam stress corrosion specimens were fabricated from 0.050 inch material and exposed at the International Nickel Company's Harbor Island (Kure Beach) Corrosion Laboratory. The specimens were stressed to approximately 90% of the 0.2% offset yield strength as determined by tensile test. Specimens were stressed in jigs having a fixed length of 7.000 inches and lengths were determined to place the middle 1/3 of the specimen under the desired stress. Specimens were exposed to sea water immersion only, sea water immersion for 6 months and in the 80' lot, and in the 80' lot only.

Data for the initial tests of the titanium alloys and coated and uncoated steel alloys are presented in Table 2-28. Additional tests were run on welded, uncoated AISI 4330M in the 80' lot to determine if the cracking reported in Table 2-28 was a result of stress corrosion or welding. The results of these tests are reported in Table 2-30.

2.6.2 Three and five inch diameter restrain welded 1/4 inch and 1.0 inch specimens of the Ti 6Al-4V and steel alloys were placed in the 80' lot to determine stress corrosion susceptibility. The residual stresses in these specimens should more closely simulate the stresses to be encountered in service than do the stresses in the bent beam specimens. The results of these tests are shown in Table 2-29. Additional restrained weld exposure results for Phase III materials are presented in Section 4.5 of the basic report.

TABLE 2-28

BENT BEAM STRESS CORROSION DATA
(JIG LENGTH - 7.0 INCHES, SPECIMENS - T = 0.050", W = 1.0", L TO OBTAIN 90% F_{ty})

MATERIAL	NO. OF SPECS.	TYPE SPEC. (1)	STRESS (KSI)	DATE IMMERSED IN SEA WATER (2)	DATE MOVED TO OR EXPOSED IN 80' LOT (3)	EXPOSURE PERIOD (DAYS)	
						FAILURE	NO FAILURE
TI 6AL-4V (5)	3 2 3 2	U U W,T W,T	127 127 127 127	3/14/62 3/14/62 3/14/62 3/14/62	9/7/62 9/7/62		To date 747 To date 747
TI 8AL-2CB-1TA (5)	3 2 3 2	U U W,T W,T	NR NR NR NR	1/30/62 1/30/62 1/30/62 1/30/62	7/25/62 7/25/62		To date 790 To date 790
AISI 4330M FOR COATING (5)	4	W,T	135	———	6/14/62	33,35,76,82[4]	
AISI 4330M COATED WITH 20 MIL MOSITES 1500 POLYURETHANE SHEET (5)	4	W,T	170.5	———	3/8/62		183 - Immersed 677 - 80' Lot 860 Total
HY 100 FOR COATING	5	U	90	———	6/11/62		To date
HY 100 COATED WITH 20 MILS MOSITES 60125 NEOPRENE (5)	5	U	90	———	7/27/62		To date

(1) U - Unwelded, W - Welded, T - Transverse weld. Unwelded specimens stress in longitudinal direction.
(2) Middle 1/3 of specimen immersed.
(3) All specimens, except as noted, were initially placed in immersed test. After a minimum of 6 months exposure, 3 specimens of each 5 specimen group were moved to the 80' lot.
(4) All failed in HAZ.
(5) Heat treatment per Table 1 Appendix D, composition per Table 1 Appendix C, and Welding per Section 2.0 Appendix D, references 2.

TABLE 2-29

RESTRAINED WELD STRESS CORROSION DATA(1)

MATERIAL	MATERIAL THICKNESS (IN)	PATCH DIAMETER (IN)	TYPE EXPOSURE	DATE EXPOSED	RESULTS FAILURE	RESULTS NO FAILURE
TI 6AL-4V(3)	1/4 1/4 1	3 5 5	80' Lot 80' Lot 80' Lot(2)	10/15/62 10/15/62 2/25/63	——— ——— ———	} None to date
TI 8AL-2CB-1TA (3)	1/4 1/4 1	3 5 5	——— ——— ———	——— ——— ———	Cracked after welding. Cracked after welding. Cracked after welding.	——— ——— ———
AISI 4330M FOR COATING (3)	1/4 1	3 5	80' Lot 80' Lot	10/15/62 10/15/62	——— ———	None to date None to date
HY 100 FOR COATING (3)	1/4 1/4	3 5	80' Lot 80' Lot	10/15/62 10/15/62	——— ———	None to date None to date

(1) Circular patch restrain welded in center of 12" x 12" plate per Table .

(2) Specimen removed from 80' Lot on 10/14/63 after 227 day exposure and immersed in sea water. Specimen was examined 1/6/65 after 449 days immersion and no damage was apparent.

(3) Heat treatment per Table 3-18, reference 3; Composition per Table 3-19 and Welding per Tables 3-14, 3-16, 3-17; reference 3.

TABLE 2-30

UNCOATED, WELDED AISI 4330M BENT BEAM STRESS CORROSION DATA (1)
(JIG LENGTH - 7.0 INCHES, SPECIMENS - T = 0.050", W = 1.0", L TO OBTAIN 90% F_{ty} AND STRESS AS NOTED)

SPECIMEN NUMBER	WELD DIRECTION (2)	TYPE EXPOSURE	STRESS (KSI) (5)	SPEC. LENGTH (IN)	DATE EXPOSED	EXPOSURE PERIOD (DAYS)	
						FAILURE/LOCATION	NO FAILURE
10	T	Sea Water Immersed (3)	155.7	7.420		—	548
11						176/Weld	—
12						176/Weld	—
13						—	548
14						176/Weld	—
15	L	Sea Water Immersed (3)	153.9	7.410		—	548
16						176/Weld	—
17						176/Weld	—
18						295/Weld	—
19						526/Weld	—
20	T	80' Lot Unprotected	155.7	7.420		20/3 4/16" from end	—
21						—	To date
22						—	
23						—	
24						—	
25	L	80' Lot Unprotected	153.9	7.410	2/5/63	—	To date
26						41/Weld	—
27						—	To date
28						—	To date
29						71/HAZ	—
30	T	80' Lot Protected (4)	153.9	7.410		—	To date
31						—	
32						—	
33						—	
34						—	
35	L	80' Lot Protected (4)	153.9	7.410		—	To date
36						—	To date
37						708/HAZ	—
38						276/HAZ	—
39						—	To date

TABLE 2-30 (Continued)

(1) Heat treatment per Table 3-18, reference 3; Composition per Table 3-19 and Welding per Table 3-11, reference 3.
(2) T - Transverse, L - Longitudinal
(3) Middle 1/3 of specimen immersed.
(4) Protected from atmosphere with polyethylene bags.
(5) Approximately 90% of F_{ty}.

2.7 EROSION-CORROSION

Resistance of materials to high velocity sea water impingement erosion-corrosion was determined using the LTV jet erosion test facility located at the International Nickel Company's Harbor Island (Kure Beach) Corrosion Laboratory, Wrightsville Beach, N.C. Metal specimens 1/2 inch in diameter and 1/4 inch thick were mounted in nylon holders and subjected to 90 knot sea water impingement for 30 days at an impingement angle of 45°. Erosion-corrosion rates were determined from specimen weight loss during exposure. Coatings were evaluated by coating AISI 4330M specimens of the same size as the nylon holders. Results were determined visually.

Erosion-corrosion data for steel and titanium alloys are presented in Table 2-31. Results for Phase II coating systems are shown in Section 2.10.2, Appendix A and for Phase III coating systems in Section 4.7 of the basic report.

TABLE 2-31

90 KNOT, 45°, SEA WATER IMPINGEMENT EROSION - CORROSION DATA

MATERIAL	UNWELDED SPECIMENS (1)							WELDED SPECIMENS (1)						
	Spec. No. (2)	Days In Test	Wt. Loss	Erosion-Corrosion Rate (MPY)	Damage	AVG. Water Velocity (Knots)	AVG. Water Temp. (F°)	Spec. No.	Days In Tests	Wt. Loss	Erosion-Corrosion Rate (MPY)	Damage	AVG. Water Velocity (Knots)	AVG. Water Temp. (F°)
TI 6AL - 4V (3)	[illegible]	30	1.[illegible] mg	0.[illegible]	No visible attack			88	11	0.4 mg	0.9	No visible attack		
	[illegible]	30	0.[illegible] mg	0.8				89	11	0.3 mg	0.7			
	[illegible]	30	1.[illegible] mg	1.0				90	11	0.5 mg	1.1			
	AVG.	30	1.1 mg	0.[illegible]		[illegible]	47	AVG.	11	0.4 mg	0.9		88	46
TI 8AL - [illegible] - 1[illegible] (3)	[illegible]	30	1.[illegible] mg	1.0	Severe; tiny pits			88	30	0.4 mg	0.3	No visible attack		
	[illegible]	30	0.4 mg	0.[illegible]				89	30	0.6 mg	0.5			
	[illegible]	30	1.[illegible] mg	1.[illegible]				90	30	0.6 mg	0.5			
	AVG.	30	1.[illegible] mg	0.[illegible]		[illegible]	51	AVG.	30	0.5 mg	0.4		88	47
HY 100 For Cladding (3)	[illegible]	30	[illegible] gm	1[illegible]	Severe pitting			NO TEST						
	[illegible]	30	[illegible] gm	114										
	[illegible]	30	[illegible] gm	134										
	AVG.	30	[illegible] gm	1[illegible]		[illegible]	54							
AISI 4130N For Cladding (3)	[illegible]	—	—	—	General corrosion on surfaces with very little pitting. Severe corrosion on sides and backs of specimens. Accuracy of rates is doubtful.			88	30	0.20 gm		General corrosion on surfaces with pitting on surface. Severe corrosion on sides and backs of specimen. Accuracy of rates is doubtful.		
	[illegible]	30	1.1[illegible] gm	[illegible]				89	30	0.20 gm				
	[illegible]	30	0.[illegible] gm	1.0				90	30	0.16 gm				
	AVG.	30	— —	— —		89	51	AVG.		0.19 gm	90		89	45

(1) 1/8 inch nozzle diameter, 45° impingement angle.
(2) 1/4 inch diameter x .75 inch specimens mounted in nylon holders.
(3) Heat treatment Table 1, Appendix B; composition Table 1, Appendix C; and welding per Section 2.0, Appendix A.

2.8 CAVITATION-CORROSION

The cavitation-corrosion resistance of materials was evaluated using the magnetostricture method at LTV and the rotating disc test at NASL. Details and results of these tests are presented in Tables 2-32 and 2-33. The magnetostricture data from Table 2-32 are plotted in Figure 2.7. The cavitation rates shown in Table 2-32 were obtained from the straight line portion of these curves.

Cavitation-erosion data for Phase II coating systems are presented in Section 2.10.3 and for Phase III systems in Section 4.7 of the basic report.

TABLE 2-32

MAGNETOSTRICTURE CAVITATION-CORROSION DATA (1)

MATERIAL (2)	TI 6AL-4V	TI 8AL-2CB-1TA		AISI 4330 FOR CLADDING	HY 100 FOR CLADDING
	CUMULATIVE WT. LOSSES (MILLIGRAMS)				
TIME \ SPEC. NO.	1	1	2	1	2
15 Min.	0	0.4	——	2.8	4.7
30 Min.	0	0.9	——	5.7	11.1
45 Min.	0	1.1	——	8.4	17.7
1 Hr.	0.3	1.3	0.5	11.8	24.3
2 Hrs.	1.4	2.9	1.3	17.8	49.5
3 Hrs.	4.2	5.4	2.7	27.9	73.1
4 Hrs.	5.6	6.4	4.3	35.3	91.0
5 Hrs.	8.1	8.5	6.3	45.2	105.4
6 Hrs.	10.3	9.7	8.2	52.5	115.2
7 Hrs.	11.7	11.7	10.2	59.4	--
8 Hrs.	14.1	13.[illegible]	[illegible]	[illegible]	[illegible]
Stabilized Rate (Mg/Hr.)	2.2	[illegible]	1.7	[illegible]	19.2
Rate (Inches/Year)	0.848	0.662	0.662	2.00	4.1[illegible]
Hardness	Rc-35	Rc-26		Rc-38	Rb-95

(1) Double Amplitude - 0.001 inches. Frequency - 22,000 CPS. Sea Water Temperature - 72 ±2°F. Specimen - 0.623 inch diameter dished. thickness varied with material density so that all specimens initially weighed the same.

(2) Heat treatment per Table 1, Appendix D; Composition per Table 1, Appendix C; and Welding per Section [illegible], reference 2.

TABLE 2-33

ROTATING DISC CAVITATION-CORROSION DATA (1)

MATERIAL	HARDNESS	WATER TYPE	CAVITATION-CORROSION RATE (ul/hr) VELOCITY (FPS) 100	125	150
TI 6AL-4V (2)	Rc-35	Sea	0	0.2	0.48
TI 8AL-2CB-1TA (2)	Rc-26	Sea	0	Scrubbing	0.51
AISI 4330M FOR CLADDING (2)	Rc-38	Fresh	Scrubbing	0.11	No test (3)
AISI 4330M FOR CLADDING (2)	Rc-38	Sea	Scrubbing	0.09	1.1
AISI 4330M FOR COATING	Rc-44	Sea	Scrubbing	Scrubbing	0.33
AISI 1016 MILD STEEL (4)	Rb-65	Fresh	0.1	0.17	1.70
AISI 1016 MILD STEEL (4)	Rb-65	Sea	0.1	0.28	2.27

(1) Naval Applied Science Laboratory Rotating Disc Test. Shaft Speed - 3200 RPM. Water Pressure - 15 PSIG.

Water Type	Flow Rate (GPM)	Inlet Temp. (°F)	Outlet Temp. (°F)
Sea	7.8	50	58
Fresh	9.5	65	72

All specimens except AISI 1016 were 1.0 inch x 0.050 inch inserts bonded in SAE 1020 discs.

(2) Heat treatment per Table 1, Appendix D; Composition per Table 1, Appendix C; and Welding per Section 2.0, Appendix D, reference 2.

(3) Insert lost during test.

(4) Data included for comparison only.

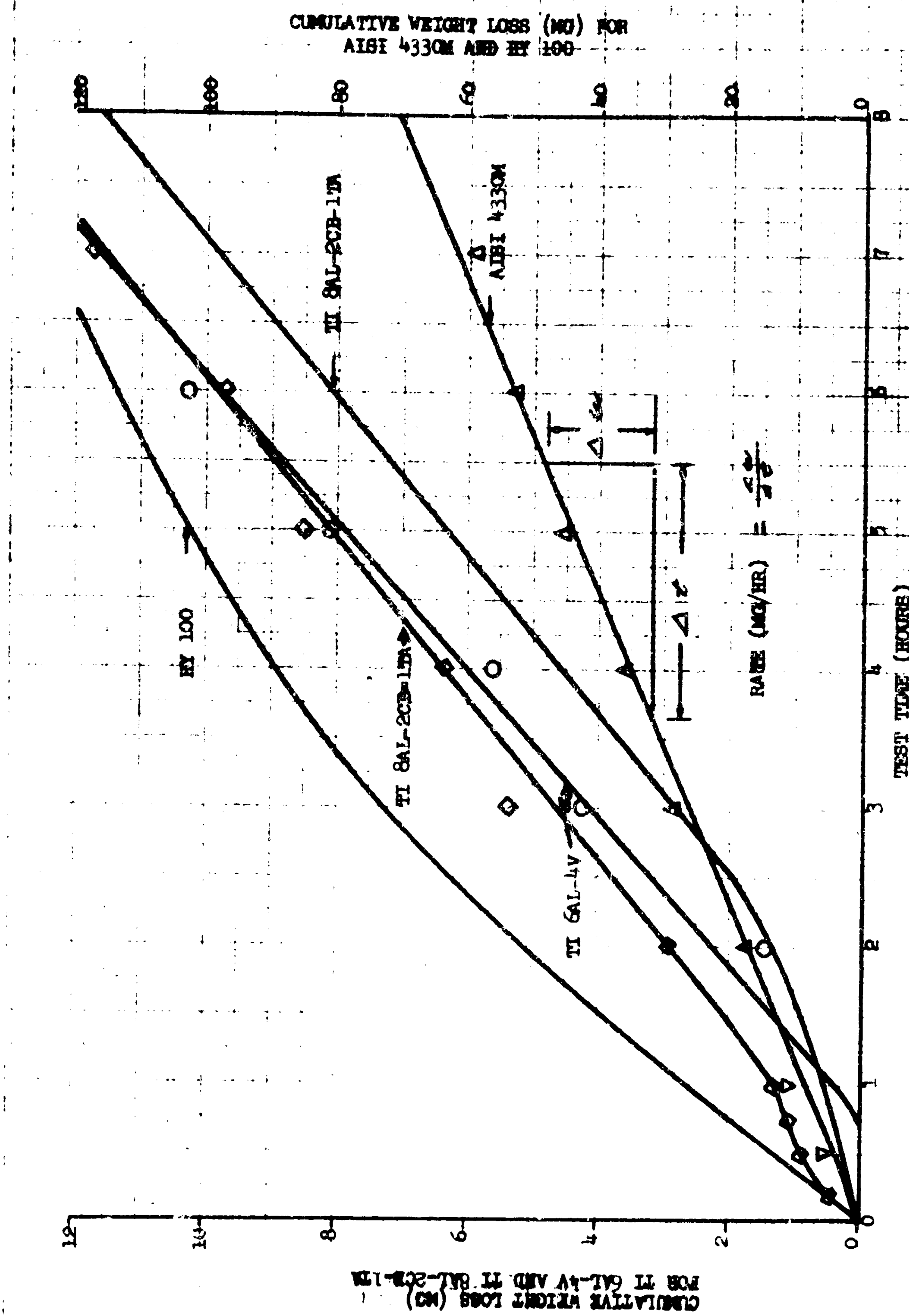


FIGURE 2.7 CUMULATIVE WEIGHT LOSS VERSUS TIME FOR MAGNETOSTRICTIVE CAVITATION-CORROSION TESTS. DATA FROM TABLE B-32.

2.9 CORROSION-FATIGUE

Rotating beam corrosion-fatigue tests were performed by the International Nickel Company at the Harbor Island (Kure Beach) Corrosion Laboratory, Test procedures and results are shown in Table 2-34 for the titanium alloys and AISI 4330M. Additional corrosion-fatigue data are presented in Sections 4.3 and 4.6 of the basic report.

ROTATING BEAM CORROSION - FATIGUE DATA (1450 CPS IN FLOWING SEA WATER)

MATERIAL	SPEC. NO.	SPEC. TYPE (1)	TEST STRESS (KSI) (2)	CYCLES X 10^{-6} (3)	TEST DIA. (IN)	BREAK DIA. (IN)	FRACTURE LOCATION	APPARENT K_t (4)	REMARKS
TI 6AL-4V(5)	1	W	72	0.021	0.463	0.430	Adj. to weld	1.5-2.0 (2)(a)	1 inch bar stock
	2	W	72	2.694	0.466	0.441			
	3	N	40	18.086	0.431	——	None	3.25 (2)(b)	1 inch bar stock
	4	N	40	15.192	0.431	——	None		
	5	W	72	0.004	0.471	0.445	In weld	1.5-2.0 (2)(a)	1 inch bar stock
	6	W	72	0.092	0.472	0.455			
	7	W	72	0.002	0.471	0.487			
TI 8AL-2CB-1TA (5)	1	U	35	10.144	0.473	——	None	——	1 inch bar stock
	2	U	35	10.119	0.471	——	None	——	
	3	U	35	10.021	0.472	——	None	——	
	4	W	66	0.018	0.468	0.459	In Weld	None assumed	1 inch plate
	5	W	66	0.026	0.466	0.458			
	6	N	37	15.000	0.431	——	None	3.25(2,b)	
AISI 4330M FOR COATING (5)	1	U	35	0.542	0.472	0.500	At tapes	——	1 inch bar stock
	2	U	35	0.524	0.472	0.502	At tapes	——	
	3	U	35	0.498	0.475	0.467	Test dia.	——	
	4	C	35	6.140	0.472	——	Edge of coating	——	
	5	C(6)	35	5.031	0.472	——		——	
	6	C	35	10.000	0.472	——	None	——	
	7	W/C	70	0.112	0.470	0.468	In weld	None (2,a) Assumed	1 inch plate
	8	W/C	70	0.108	0.470	0.465			
	9	N/C	22	15.822	0.431	——	None	3.25 (2)(b)	
	10	N/C	22	15.359	0.431	——	None		

(1) W - Welded, W/C - Welded and coated (with 20 mils Mosites 1500 polyurethane sheet), C - Coated (with 20 mils Mosites 1500 polyurethane sheet), N - Notched, N/C - Notched and coated with 20 mils Mosites 1500 polyurethane sheet, U - Unwelded.

(2) Test stress levels were established as follows: (a) Welded-unnotched levels were selected by assuming that the presence of the weld would have no influence on the fatigue strength of the material. (b) Notched-unwelded stress levels were selected through the use of published notch fatigue data and, where applicable, these stress levels were modified to reflect the effects of corrosion as determined in earlier tests. The notch geometry provides a theoretical $K_5 = 3.25$.

TABLE 2-34 (CONTINUED)

(3) Maximum of 10^7 cycles required.

(4) During testing, the welded-unnotched specimens failed at much lower cycle lives than had been anticipated. This is undoubtedly due to the fact that the presence of the welds does not create an effective notch thus lowering the fatigue life of the part. The values in this column are representative of the effective notch value for each of the welded materials from comparison of the present test results with published fatigue data for unwelded material in non-corrosive environment.

(5) Heat treatment per Table 1, Appendix D, Composition per Table 1, Appendix C; and Welding per Section 2.0 Appendix D, reference 2.

(6) Coating applied per Section 2.10.4.1A, Appendix A.

2.10 COATING SYSTEM TEST RESULTS

2.10.1 STATIC IMMERSION

Sea water immersion tests of coating systems were performed much in the same manner as previously described in Section 2.5, Appendix A for uncoated materials. Weight gains and losses were recorded for coated specimens during each reporting period, however, evaluation was accomplished by visual observation.

Results for the two primary coating systems evaluated in Phase II are presented in Table 2-35. The specimens removed at monthly intervals are shown in Figure 2.8 and 2.9.

Because of the rapid degradation of 17-4PH (H 1025) and (H 1075) in Phase II static corrosion tests, additional welded 17-4PH (H 1025) specimens were exposed (1) Uncoated, (2) 100% Neoprene Coated, (3) 95% Neoprene Coated and (4) 90% Neoprene Coated. These specimens were exposed to determine if (1) the previous Phase II static corrosion data for welded 17-4PH (H 1025) were reproducible and (2) to determine if the static corrosion damage to welded 17-4PH (H 1025) was reduced when the material was exposed fully coated and 5 and 10% of the surface area uncoated. The results of these tests, presented in Tables 2-36 and 2-37, indicate both of the above points are true. The condition of one specimen of each type after the 12th monthly removal is shown in Figure 2.10.

The GAEC #1012/Magna Laminac X-500 PC(H)-1 coating system was also exposed to static immersion test. The results are presented in Table 2-38 and the condition of specimens after the 12th monthly removal and 12 months continuous immersion are shown in Figure 2.11.

Static immersion data for Phase III coating systems are included in Section 4.7 of the basic report.

TABLE 2-35

SEA WATER STATIC IMMERSION DATA FOR WELDED AND COATED AISI 4330M AND HY-100 STEEL(1)

MONTHS EXPOSED	AISI 4330M COATED WITH 20 MILS MOSITES 1500 AND PRO-SEAL 793 POLYURETHANE — SPECIMEN NO. 1 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 1 — COATING CONDITION	SPECIMEN NO. 2 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 2 — COATING CONDITION	% FOULED	AVG. WATER TEMP. (°F)	HY-100 COATED WITH 20 MILS MOSITES 60125 NEOPRENE — SPECIMEN NO. 1 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 1 — COATING CONDITION	SPECIMEN NO. 2 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 2 — COATING CONDITION	% FOULED	AVG. WATER TEMP. (°F)
REMOVED MONTHLY(7)												
1	-0.1	Good	-0.1	Good	45	67	+1.6	Good	+1.5	Good	5	71
2	+0.[illegible]	Good	+0.8	Good	30	74	+0.7	Loose at one corner	+0.9	Good	10	58
3	-0.[illegible]	Good	-0.3	Good	25	77	-0.6	Loose at one corner	-0.7	Loose at one corner	5	52
4	-0.5	Rust at one corner	-0.5	Break in insulator	50	81	+0.8	Loose at one corner	+0.8	Loose at one corner	5	44
5	+0.3	Rust at one corner	+0.3	Rust at one corner	25	80	-0.4	Loose at 1 corner, rust	-0.4	Loose at 1 corner, rust	0	43
6	+0.2	Rust along one edge(5)	+0.2	Loose at one edge(5)	15	71	+1.6	Loose at 1 corner, rust	+0.5	Loose at 1 corner, rust	5	48
7	+0.9	Loose at 1 corner(2)	+0.9	Rust along one edge(5)	5	58	+0.5	Loose at 1 corner, rust Blistering on surface.	+0.4	Loose at 1 corner, rust Blistering along edge	35	57
8	-0.[illegible]	Loose at 1 corner	-0.7	Loose on 1 side(2)	5	52	+0.5	Numerous breaks and blisters on both surfaces	+0.4	Numerous breaks and blisters on both surfaces	90	64
9	+1.0	Loose on 1 side(2)	+1.3	Loose on 1 side(2)	5	44	+1.5	Breaks along edges	+1.5	Breaks along edges	75	70
10	0.0	Loose on 1 side	0.0	Loose on 1 side	0	43	+0.3	Breaks along edges	-0.5	Crevice cor. at breaks	75	76
11	+1.8	Loose on 1 side, rust(2)	+1.9	Loose on 1 side, rust(2)	5	48	+1.0	Crevice cor. at breaks	+1.9	Crevice cor. at breaks	75	78
12	-0.3	Loose, rusting(2) Blisters(3)	+0.2	Loose, rusting(2) Blisters(3)	35	57	0.0	Crevice cor. at breaks	0.0	Crevice cor. at breaks	50	73
13	+1.1	Loose over 15% of area(2) Increased blistering(3)	+1.0	Loose(2) Increased blistering(3)	90	64	+0.8	Severely blistered	+0.7	Severely blistered	25	66
14	+1.4	Loose over 25% of area(2) Increased blistering(3)	+1.2	Loose over 10% of area(2) Increased blistering(3)	75	70	-4.6	Severely blistered Accelerated corrosion	-2.8	Severely blistered Accelerated corrosion	25	58
15	-7.2	Loose over 100% of area(2) Increased blistering(3)	+0.4	Loose over 65% of area(2) Increased blistering(3)	75	76	+0.7	Accelerated corrosion	+0.9	Accelerated corrosion	10	45
16	-5.6	Loose over 100% of area(2) Increased blistering(3)	-9.1	Loose over 100% of area(2) Increased blistering(3)	60	78	-0.1	Accelerated corrosion	0.0	Accelerated corrosion	25	45
17	-12.0	Rapid overall cor.(2)	-4.7	Rapid overall cor.(2)	50	78	+0.4	Accelerated corrosion	+1.1	Accelerated corrosion	90	41
18(8)	-3.6	Crevice cor. at edges(3)	-3.9	Crevice cor. at edges(3)	25	66	-0.8	Accelerated corrosion	-0.8	Accelerated corrosion	N.R. (4)	52
CONTINUOUS IMMERSION												
6	+0.9	Breaks along edge, rusting(5)	+0.6	Breaks along edge, rusting(5)	90	N.R. (4)	+3.4	Loose along one edge	+3.4	Blistered and loose along one edge	100	51
12	+0.3	Good on surfaces except one small loose area. Rusting along edges(5)	-0.3	Loose over 1/2 of one surface. Rusting at ruptured blister	100	62	+4.2	Good. Coating intact. No rusting evident	+5.3	Good. Coating intact. No rusting evident	100	61
24	+0.6	Few blisters on all surfaces. Loose over 1/2 of one surface.	+0.9	Blisters on all surfaces. Breaks along edges. Loose over 80% of 1 surface.	100	N.R. (4)	19.3 (6)	Numerous breaks. 75% of surface blistered.	12.3	50-60% of surface blistered. Numerous breaks.	100	61

(1) See page 1.74A for coating application procedures. Heat treatment per Table 1, Appendix D, composition per Table 1, Appendix C and welding per Section 2.0, Appendix D, reference 2. (2) Side coated with Pro-Seal 777P primer and Pro-Seal 793 top coat. (3) Side coated with Mosites 1500. (4) Not reported. (5) At seam joining Mosites 1500 and Pro-Seal 793. (6) High weight gain due to mud and sand trapped under coating. (7) Specimens removed, cleaned, inspected and returned to test each month. (8) See figures 2.8 and 2.9.

TABLE 2-36
SEA WATER STATIC IMMERSION DATA FOR WELDED, 100% UNCOATED AND WELDED, 100% MOISTES 60125
NEOPRENE COATED 17-4PH (H 1025) SPECIMENS REMOVED MONTHLY(1)

MONTHS EXPOSED (3)	WELDED 100% COATED WITH 20 MILS MOSITES 60125 NEOPRENE(2) — SPECIMEN NO. 1 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 1 — COATING CONDITION	SPECIMEN NO. 2 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 2 — COATING CONDITION	WELDED, 100% UNCOATED — SPECIMEN NO. 1 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 1 — CONDITION	SPECIMEN NO. 2 — WT. GAIN OR LOSS (GMS)	SPECIMEN NO. 2 — CONDITION	% FOULED	AVG. WATER TEMP. (°F)
1	•	Good	•	2" break at edge, loose over 50% of surfaces on 1 side.	4.2	Pits - 124, 190 & 284 mils	2.2	7/8" perforation in weld	5	71
2	+0.9	Loose over 50% of surface on one side.	+2.2	Loose over 90% of surface on one side.	0.9	Pit - 200 mils, 1 perf. above weld, 1/4" x 5" corroded area at weld edge.	2.7	Pits - 100 & 140 mils, 3/16" x 1/2" corroded area at weld edge.	5-10	58
3	-0.5	Loose over 50% of surface on one side.	+0.8	2 1/2" breaks at edge, loose on one side.	1.4	Pit - 200 mils, perf. above weld, 5/16" x 1/2" corroded area at weld edge.	1.3	Pits - 100 & 140 mils, 3/16" x 13/16" corroded area at weld edge.	5	52
4	+0.7	Loose over 50% of surface on one side.	[illegible]	2 1/2" breaks at edge, loose on one side.	0.0	Pit-202 mils, 2 perf. in HAZ.	0.0	Pits-100 & 140 mils, 3/16" x 13/16" perf. in HAZ	5	44
5	-0.3	Loose over 50% of surface on one side.	[illegible]	2 1/2" breaks at edge, loose on one side, & rusting under coating.	0.0	Pit-202 mils, 2 perf. in HAZ.	0.0	Pits-100 & 140 mils, 3/16" x 13/16" perf. in HAZ	0	43
6	+0.3	Loose over 50% of surface on one side.	+0.1	2 1/2" breaks at edge, loose on one side, & rusting under coating.	0.0 (6)	Pit-202 mils, 2 perf. in HAZ.	0.0 (6)	Pits-100 & 140 mils, 3/16" x 13/16" perf. in HAZ	5	48
[illegible]	+0.4	Loose over 50% of surface on one side.	[illegible]	2 1/2" breaks at edge, loose on one side, & rusting under coating.	0.0	Pit-202 mils, 2 perf. in HAZ.	0.1	Pits-100 & 140 mils, 3/16" x 13/16" perf. in HAZ	30-40	57
[illegible]	[illegible]	Loose over 50% of surface on one side.	[illegible]	Several breaks, loose on one side, rusting under coating.	1.2	Pit-208 mils, 2 perf. in HAZ, 1/8" x 1/2" & 1/8" x 15/16	0.9	Pits-100 & 140 mils, 1/4" x 13/16" perf. in HAZ.	80	64
[illegible]	[illegible]	Loose over 50% of surface on one side.	[illegible]	Several breaks, loose over 90% of surface on 1 side.	2.6	Pits-140 & 200 mils, 2 perf. in HAZ 1/8" x 1/2" & 1/8" x 1 1/2"	2.7	Pits-78, 100 & 140 mils, 2 perf. in HAZ 3/16" x 13/16 & 1/16" x 1/4"	75	70
10	-1.7	Loose over 50% of surface on one side.	[illegible]	3" break at 1 edge with crevice cor. Loose over 90% of surface on 1 side.	[illegible]	Pits-142 & 208 mils, 2 perf. in HAZ-1/8" x 1/2" & 1/8" x 1 1/2"	3.8	Pits-80, 102 & 140 mils, 2 perf. in HAZ 3/16" x 1 5/16" & 1/16 x 1/2"	75	76
11	[illegible]	Loose over 50% of surface on one side & break at edge with crevice corrosion.	-0.5	Loose over 90% of surface on one side, several breaks with crevice cor.	5.2	Pits-142 & 208 mils, 2 perf. in HAZ 1 9/16" & 1 1/16"	4.9	Pits-numerous to 143 mils, 2 perf. in HAZ 1/2" x 13/16" & 1 5/8" long.	75	78
12(4)	+0.[illegible]	Loose over 50% of surface on one side & break at edge with crevice corrosion.	0.[illegible]	Loose over 90% of surface on one side, several breaks with crevice cor.	5.3 (6)	Pits-142 & 208 mils, perf. nearly sever panel in HAZ TEST TERMINATED	6.3 (6)	Pits-numerous to 143 mils, 2 perf. in HAZ 13/16" x 5/8" & 1 15/16" long.	50	73

TABLE 2-36 (CONTINUED)

SEA WATER STATIC IMMERSION DATA FOR WELDED, 100% UNCOATED AND WELDED, 100% MOSITES 60125 NEOPRENE COATED 17-4PH (H 1025) SPECIMENS REMOVED MONTHLY(1)

MONTHS EXPOSED (3)	WELDED 100% COATED WITH 20 MILS MOSITES 60125 NEOPRENE(2)				WELDED, 100% UNCOATED				% FOULED	AVG. WATER TEMP. (°F)
	SPECIMEN NO. 1		SPECIMEN NO. 2		SPECIMEN NO. 1		SPECIMEN NO. 2			
	WT. GAIN OR LOSS (GMS)	COATING CONDITION	WT. GAIN OR LOSS (GMS)	COATING CONDITION	WT. GAIN OR LOSS (GMS)	CONDITION	WT. GAIN OR LOSS (GMS)	CONDITION		
13	-0.1	Loose over 50% of surface on one side & break at edge with crevice corrosion.	+0.6	Loose over 90% of surface on one side, several breaks with crevice cor.			3.6	Pits-numerous to 143 mils, 2 perf. in HAZ 1 15/16" & 2 1/8"	25	66
14	-4.1	Loose over 50% of surface on one side, corrosion progressing at 2" breaks at edge.	-5.9	Loose over 90% of surface on one side, corrosion progressing at numerous breaks.			5.5	Pits-numerous to 143 mils, 2 perforations in HAZ each 2 3/8"	25	58
15	+1.6	Loose over 50% of surface on one side, corrosion progressing at 2" breaks at edge.	+0.9	Loose over 90% of surface on one side, corrosion progressing at numerous breaks.			0.1	Pits-numerous to 143 mils, 2 perforations in HAZ each 2 3/8"	10	45
16	-0.9	Loose over 50% of surface on one side, corrosion progressing at 2" breaks at edge.	+0.4	Loose over 90% of surface on one side, corrosion progressing at numerous breaks.			0.3	Pits-numerous to 143 mils, 2 perforations in HAZ each 2 3/8"	25	45
[illegible]	+1.6	Loose over 50% of surface on one side, corrosion progressing at 2" breaks at edge.	+0.8	Loose over 90% of surface on one side, corrosion progressing at numerous breaks.			0.1	Pits-numerous to 143 mils, 2 perforations in HAZ each 2 3/8"	90	47
18	-1.9	Loose over 50% of surface on one side, corrosion progressing at 2" breaks at edge.	-1.7	Loose over 90% of surface on one side, corrosion progressing at numerous breaks.			0.4 (6)	Pits-numerous to 143 mils, 2 perforations in HAZ each 1/4" x 2 3/8"	N.R. (5)	52

(1) Heat treatment per Table 1, Appendix D, Composition Table 1, Appendix C and Welding per Section 2.0 Appendix D, reference 2.
(2) See page [illegible] for coating application procedure.
(3) Specimens removed, cleaned, inspected and returned to test each month.
(4) See Figure [illegible].
(5) Not reported.
(6) Cumulative weight loss: Specimen No. 1 - 6 months 6.5 grams, 12 months 24.5 grams, Specimen No. 2 - 6 months 6.2 grams, 12 months 24.7 grams, 18 months 34.7 grams.

TABLE 2-37

SEA WATER STATIC IMMERSION DATA FOR WELDED 17-4PH (H-1025) SPECIMENS 90% COATED (10% UNCOATED) AND 95% COATED (5% UNCOATED) WITH 20 MILS MOSITES 60125(1) NEOPRENE COATING, REMOVED MONTHLY

MONTHS EXPOSED (4)	90% COATED WITH 20 MILS MOSITES 60125 NEOPRENE(2) — SPECIMEN NO. 1 — WT. GAIN OR LOSS (GMS)	CONDITION	SPECIMEN NO. 2 — WT. GAIN OR LOSS (GMS)	CONDITION	95% COATED WITH 20 MILS MOSITES 60125 NEOPRENE(2) — SPECIMEN NO. 1 — WT. GAIN OR LOSS (GMS)	CONDITION	SPECIMEN NO. 2 — WT. GAIN OR LOSS (GMS)	CONDITION	% FOULED	AVG. WATER TEMP. (°F)
1	*	Coating loose along 1 edge	*	2 blisters adjacent to uncoated area	*	Coating loose at 1 corner	*	Coating loose over 75% of area on fully coated side, 2 breaks	5	71
2	+0.9	Coating loose over 25% of fully coated side	+0.5	Coating loose at 2 points on fully coated side	+2.1	Coating loose over 50% of fully coated side	+7.6	Coating loose over 90% of fully coated side	5-10	58
3	-1.0	Same as above	-0.[illegible]	Same as above	-0.9	Same as above only 95%	-4.7	Same as above	5	52
4	+0.9	Coating loose over 25% of fully coated side, 3/4" break	+0.[illegible]	Same as above	+1.3	Same as above	-0.6	Same as above	5	44
5	-0.[illegible]	Coating loose over 25% of fully coated side, 3/4" break, rust under coating	[illegible].4	Same as above	-0.4	Same as above	-0.9	Coat loose over 95% of fully coated side, several breaks	0	43
6	+0.[illegible]	Same as above	+0.3	Same as above	+0.9	Same as above	+0.5	Same as above	5	48
[illegible]	+0.2	1" break at coating edge, rust under cut edge(4)	+0.2	Same as above	+0.8	Same as above	+0.2	Same as above	30-40	57
8	[illegible]	1" break at coating edge, rust under cut edge(6), incipient pitting	+0.2	Same as above	-0.1	Same as above	+2.2	Coat loose over 95% of fully coated side, several breaks, blisters on 95% coated side	80	64
9	+0.5	1" break at coating edge, crevice cor. under cut edge at weld	+0.5	Coating loose at [illegible] points on fully coated side, lifting at cut edge, crevice cor. under cut edge in HAZ	+1.0	Coating loose over 95% of fully coated side, lifting along cut edge	-0.7	Coat loose over 95% of fully coated side, several breaks, blisters on 95% coated side, lifting along cut edge	75	70
10	+0.[illegible]	Several large blisters on fully coated side, crevice cor. at cut edge	[illegible]	Several large blisters on fully coated side, crevice cor. at cut edge in HAZ	+0.2	Several large blisters on fully coated side, crevice cor. at cut edge	-0.3	Coating blistered and loose on fully coated side, crevice cor. at cut edge	75	76
[illegible]	+0.[illegible]	Same as above	[illegible]	Same as above	-1.3	Severe crevice cor. at cut edge	+1.2	Same as above	75	78
[illegible]	[illegible]	Same as above		Several blisters on both sides, crevice cor. at cut edge in HAZ	-0.9	Same as above	-1.0	Same as above	50	73
[illegible]	+0.[illegible]	Several large blisters on fully coated side, lifting at cut edge, severe crev. cor.	0.[illegible]	Severe crevice cor. along cut edge in weld & HAZ	+0.8	Same as above	0.0	Same as above	25	66
[illegible]	[illegible]	Crevice cor. progressing at several points along cut edge, especially in HAZ	[illegible]	Crevice cor. progressing at several points along cut edge especially in HAZ	-4.9	Same as above	-4.7	Same as above	25	58
[illegible]	+0.[illegible]	Same as above	[illegible]	Same as above	+0.6	Same as above	+1.7	Same as above	10	45
[illegible]	[illegible]	Same as above	[illegible]	Same as above	+0.5	Same as above	+0.5	Same as above	25	45
[illegible]	+0.[illegible]	Same as above	[illegible]	Same as above	-5.1	Same as above	0.0	Same as above	90	47
[illegible]	[illegible]	Same as above	[illegible]	Same as above	+3.7	Same as above	-1.3	Same as above	N.R. (5)	52

TABLE 2-37 (CONTINUED)

(1) Heat treatment per Table 1, Appendix D; Composition per Table 1, Appendix C and Welding per Section 2.0, Appendix D, reference 2.

(2) See page 1.74A for coating application procedure.

(3) Specimens removed, cleaned, inspected and returned to test each month.

(4) See Figure 2.10.

(5) Not Reported

(6) Cut edge refers to edge of coating adjacent to uncoated area.

TABLE [illegible]

SEA WATER STATIC IMMERSION DATA FOR UNWELDED AISI 4130M STEEL COATED WITH
[illegible] EPOXY PRIMER AND MAGNA LAMINAR X-500 CERAMIC FRIT FILLED POLYURETHANE TOP COAT(1)

MONTHS EXPOSED	REMOVED MONTHLY(2) Specimen No. 1 WT. GAIN OR LOSS (GM)	Specimen No. 1 COATING CONDITION	Specimen No. 2 WT. GAIN OR LOSS (GM)	Specimen No. 2 COATING CONDITION	% FOULED	AVG. WATER TEMP. (°F)
[illegible]	[illegible]	Good	[illegible]	Good	1	21.
[illegible]	[illegible]	Good	[illegible]	Good	[illegible]	14.3
[illegible]	[illegible]	Good	-0.4	1/[illegible] blister on one side	5	[illegible].1
[illegible]	[illegible]	[illegible] blistered [illegible]	[illegible]	[illegible]% blistered to 1/[illegible]	5	[illegible]
[illegible]	[illegible]	[illegible] blistered [illegible]	+0.4	[illegible]% blistered to 1/4[illegible]	[illegible]	[illegible].3
[illegible]	[illegible]	Blisters rupturing, rusting	[illegible]	Blisters rupturing, rusting	[illegible]	d.7
[illegible]	[illegible]	Blisters [illegible] rupturing, rusting	[illegible]	Blisters rupturing, rusting	35	13.8
[illegible]	[illegible]	[illegible]	[illegible]	Increased blister rupture and rusting	75	[illegible].0
[illegible]	[illegible]	[illegible]	[illegible]	Increased blister rupture and rusting	[illegible]	21.3
[illegible]	[illegible]	[illegible]	[illegible]	Cracking, rusting	[illegible]	24.3
[illegible]	[illegible]	[illegible]	[illegible]	Increased cracking and rusting	75	[illegible]
[illegible]	[illegible]	No change	[illegible]	No change	50	22.[illegible]
[illegible]	[illegible]	No change	[illegible]	No change	2[illegible]	[illegible]
[illegible]	[illegible]	Increased cracking and rusting	[illegible]	Increased cracking and rusting	[illegible]	14.6
[illegible]	[illegible]	No change	+0.[illegible]	No change	[illegible]	[illegible].2
[illegible]	[illegible]	No change	[illegible]	No change	[illegible]	[illegible].4
[illegible]	[illegible]	Numerous cracks with rusting	[illegible]	Numerous cracks with rusting	[illegible]	[illegible].1
[illegible]	[illegible]	No change	[illegible]	No change	N.R.(3)	[illegible].2
CONTINUOUS IMMERSION						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] No breaks [illegible]	100	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] blistered. Some cracking and rusting	100	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Severely blistered. Numerous cracks with rusting.	100	16.3

(1) [illegible] Corp. [illegible] Epoxy Primer and Magna Coatings & Chemical Corp. Laminar X-500 Polyurethane Top Coat Spray Applied by Grumman [illegible] Engineering [illegible] (2) Specimens removed, cleaned, inspected and returned to test each month. (3) Not Reported.

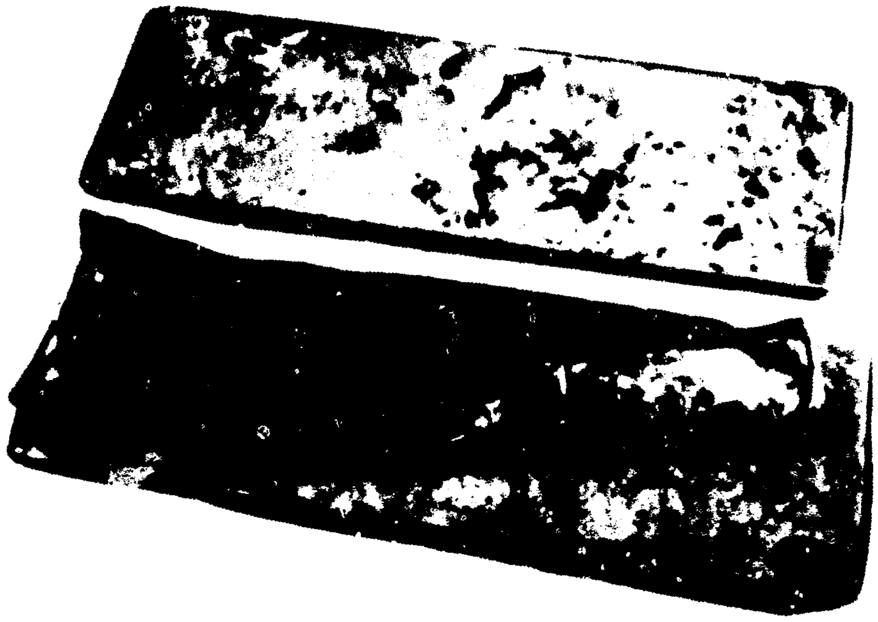


FIGURE 2.5. WELDED AISI -330M COATED WITH 20 MILS MOSITES 1500 PRIMER, ADHESIVE AND CALENDERED POLYURETHANE SHEET AND COAST PRO-SEAL 777P PRIMER AND 793 SPRAYED POLYURETHANE TOP COAT AFTER 18TH MONTHLY REMOVAL FROM SEA WATER IMMERSION. UPPER SURFACES COATED WITH COAST PRO-SEAL 777P AND 793.

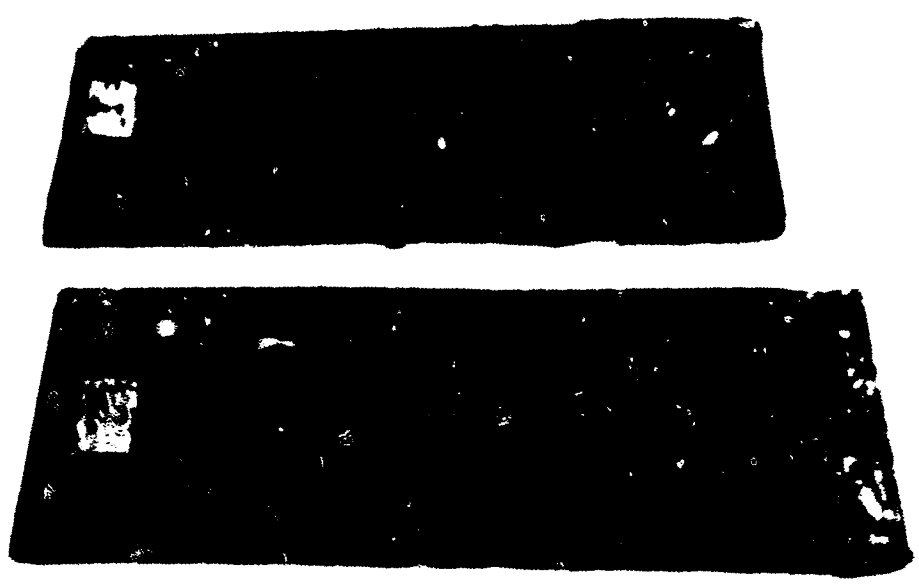
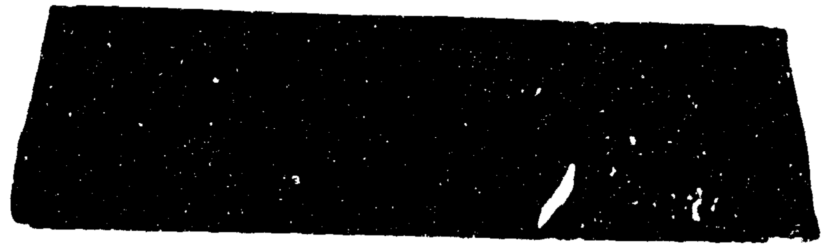
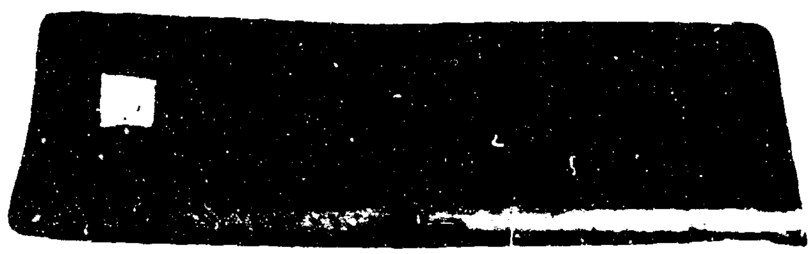


FIGURE 2.9. WELDED HY-100 COATED WITH 20 MILS MOSITES 5010 PRIMER, ADHESIVE AND CALENDERED NEOPRENE SHEET AFTER 18TH MONTHLY REMOVAL FROM SEA WATER IMMERSION.

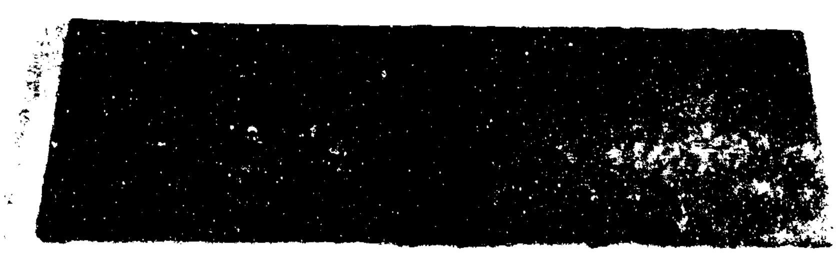


100% COATED



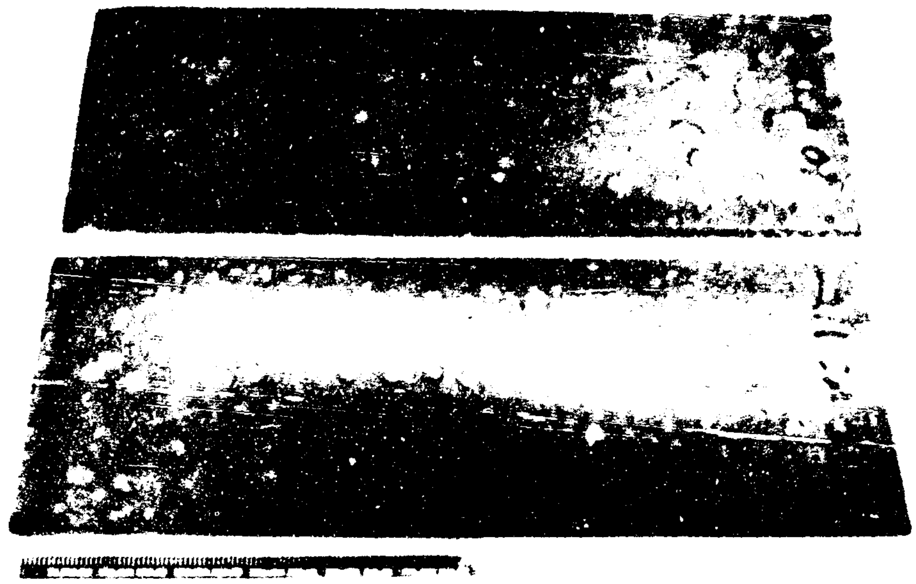
95% COATED

90% COATED



UNCOATED

FIGURE 2.10. UNCOATED, 90%, 95% AND 100% MOSITES 60125 NEOPRENE COATED WELDED 17-4PH (H-1025) SPECIMENS AFTER 12TH MONTHLY REMOVAL FROM SEA WATER IMMERSION.



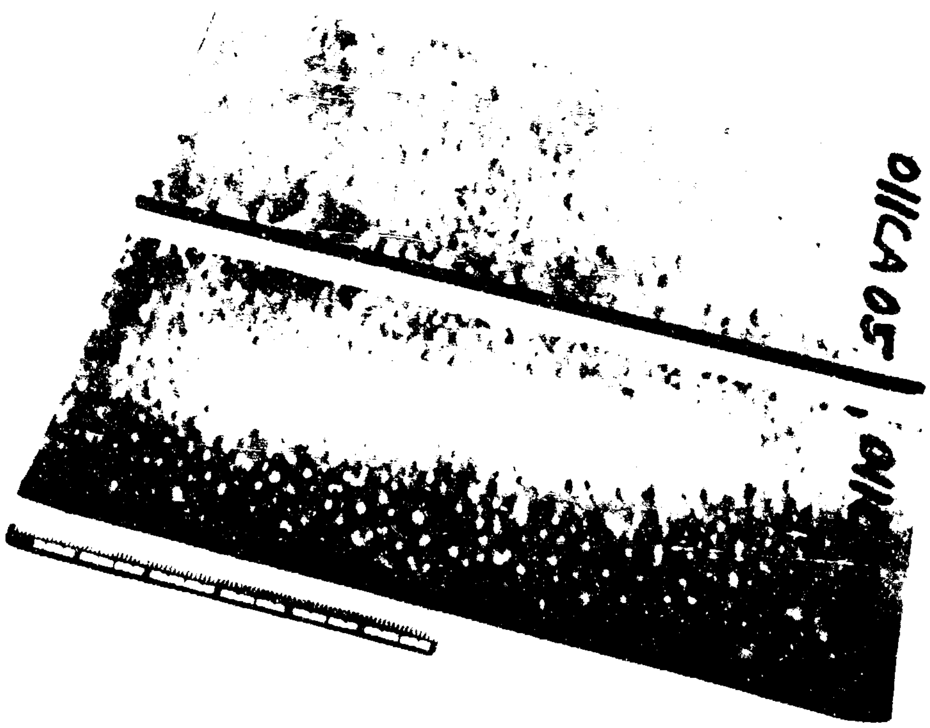


FIGURE [illegible]. GARY #10[illegible] EPOXY PRIMER/MAGNA LAMINAR X-500 [illegible] AFTER STATIC IMMERSION SPECIMENS. [illegible] THICK[illegible] - [illegible] MILS. TOP: SPECIMENS REMOVED MONTHLY AFTER [illegible] REMOVAL. BOTTOM: SPECIMENS REMOVED AFTER [illegible] MONTHS CONTINUOUS IMMERSION.

2.10.2 SEA WATER IMPINGEMENT

Phase II coating systems were subjected to 90 knot sea water impingement as described in Section 2.7, Appendix A. Details of the coating systems and test results are presented in Table 2-39.

Results of 90 knot sea water tests on Phase III coating systems are shown in Section 4.7 of the basic report.

TABLE 2-39
90 KNOT, 45°, SEA WATER IMPINGEMENT DATA FOR COATINGS APPLIED ON
EPOXY-GLASS LAMINATE AND AISI 4330M STEEL

COATING TYPE	VENDOR AND COATING DESIGNATION (1)	COATING THICKNESS	COATING HARDNESS (SHORE A OR D)(2)	MATERIAL COATED	SURFACE PREPARATION	APPLICATION METHOD	RESULTS(4)	AVERAGE WATER TEMP
Neoprene sheet, calendered and uncured	Mosites 60125 sheet, Pro-Seal 77/P Primer(3)	20	65A	Epoxy-Glass Laminate	(3)	(3)	1-Failed, 492 hrs; 1-failed, 720 hrs. Specimens previously exposed for 720 hrs without failure.	[illegible]
Neoprene sheet, calendered and uncured	Mosites 60134A sheet, primer and adhesive (L)	20	58A	Epoxy-Glass Laminate	Vapor Honed	Pressure-temperature bonded and cured after laminate cure.	2-Failed, 284 hrs.	
Neoprene sheet, calendered and uncured	Mosites 60125 sheet, Pro-Seal 77/P Primer(3)	20	65A	Epoxy-Glass Laminate	(3)	(3)	1-Failed, 46 hrs.	
Neoprene sheet, calendered and uncured	Mosites 60125 sheet, Pro-Seal 77/P Primer(L)	20	65A	4330M	Alkaline Cleaned	Pressure-temperature bonded and cured	2-Failed, 4[illegible] hrs.	
Neoprene sheet, calendered and uncured	Mosites 60125 sheet, Pro-Seal 77/P Primer(L)	20	65A	4330M	Grit Blast, 3 Mils Flame Sprayed 110 Aluminum	Pressure-temperature bonded and cured.	2-Failed, 4[illegible] hrs.	
Neoprene sheet, calendered and uncured	Mosites 60134A sheet, Primer and Adhesive(L)	25	[illegible]A	4330M	Grit Blast	Pressure-temperature bonded and cured.	2-Failed, 147 hrs, 1-failed, 95 hrs.-1 specimen retested failed, 284 hrs	
Neoprene, liquid, 2 component	NASL ML-C 570, Bostick 1007 Primer (V)	30	70-80A	4330M	Grit Blast, 3 Mils Flame Sprayed 1100 Aluminum	Brush, room temperature cure	1-failed, 45 hrs	
Neoprene, liquid, 2 component	NASL ML-C 570 Bostick 1007 Primer (V)	30	70-80A	4330M	Grit Blast	Brush, room temperature cure. (Primer and adhesive used not known)	2-No failure, 721 hrs., 1-failed, 547 hrs.	
Neoprene sheet, calendered and uncured	Mosites 60175A (V)	20	43	4330M	Grit Blast, 3 Mils Flame Sprayed 1100 Aluminum	Pressure-temperature bonded and cured. (primer and adhesive used not known)	1-failed, 715 hrs.	
Neoprene sheet, calendered and uncured	Mosites 60175B (V)	20	45	4330M	Grit Blast, 3 Mils Flame Sprayed 1100 Aluminum	Pressure-Temperature bonded and cured. (Primer and adhesive used not known)	1-failed, 113 hrs.	

TABLE [illegible] (CONTINUED)

COATING TYPE	VENDOR AND COATING DESIGNATION (1)	COATING THICKNESS	COATING HARDNESS (SHORE A [illegible])(2)	MATERIAL COATED	SURFACE PREPARATION	APPLICATION METHOD	RESULTS(4)	[illegible]
Neoprene sheet, calendered and uncured	Mosites [illegible]C (V)	[illegible]	[illegible]	[illegible]OM	Grit Blast, 3 Mils Flame Sprayed 1100 Aluminum	Pressure-Temperature bonded and cured. (Primer and adhesive used not known.)	1-Failed, 42 hrs.	
Neoprene sheet, calendered and uncured	Mosites [illegible]A (V)	[illegible]	[illegible]	[illegible]OM	Grit Blast	Pressure-temperature bonded and cured. (Primer and adhesive used not known.)	1-Failed, 42 hrs.	
Neoprene sheet, calendered and uncured	Mosites [illegible]B (V)	[illegible]	[illegible]	[illegible]OM	Grit Blast	Pressure-temperature bonded and cured. (Primer and adhesive used not known.)	1-Failed, [illegible] hrs.	
Neoprene sheet, calendered and uncured	Mosites [illegible]C (V)	[illegible]	[illegible]	[illegible]OM	Grit Blast	Pressure-temperature bonded and cured. (Primer and adhesive used not known.)	1-Failed, [illegible] hrs.	
Polyurethane sheet, calendered and uncured	Mosites [illegible] sheet, primer and adhesive([illegible])	[illegible]	[illegible]A	[illegible]OM	Grit Blast	Pressure-temperature bonded and cured.	1-Failed, [illegible] hrs; 1-Failed, [illegible] hrs; 1-Failed, [illegible] hrs.	
Polyurethane sheet, calendered and uncured	Mosites [illegible] sheet, primer and adhesive([illegible])	[illegible]	[illegible]	[illegible]OM	Alkaline Cleaned	Pressure-temperature bonded and cured.	[illegible]-Failed, [illegible] hrs.	
Polyurethane sheet, calendered and uncured	Mosites [illegible] sheet, primer and adhesive([illegible])	[illegible]	[illegible]A	4330M	Grit Blasted	Pressure-temperature bonded and cured. 2 specimens each were tested with unbroken coating, horizontal scribe to base metal and material scribe to base metal	6-Failed, [illegible] hrs.	
Polyurethane, cured sheet	B.F. Goodrich Estane (V)	20	[illegible]A	4330M	Grit Blast, 3 Mils Flame Sprayed 1100 Aluminum	Pressure bonded. (Primer and adhesive used not known)	1-Failed, 155 hrs., 1-Failed [illegible] hrs.	
Polyurethane, cured sheet	B.F. Goodrich Estane (V)	20	[illegible]A	4330M	Grit Blasted	Pressure bonded. (Primer and adhesive used not known)	2-No failure, 20 hrs.	

TABLE [illegible] (CONTINUED)

COATING TYPE	VENDOR AND COATING DESIGNATION (1)	COATING THICKNESS	COATING HARDNESS (SHORE A OR D)(2)	MATERIAL COATED	SURFACE PREPARATION	APPLICATION METHOD	RESULTS(4)
Polyurethane, liquid, [illegible] component	Mosites [illegible] (V)	[illegible]	[illegible]	4130M	Grit Blast, [illegible] Mils Flame Sprayed [illegible] Aluminum	Spray, room temperature cure. (Primer and adhesive used not known)	1-No failure, [illegible] hrs.
Polyurethane, liquid, [illegible] component	Mosites [illegible] (V)	[illegible]	[illegible]	4130M	Grit Blast	Same as above	1-Failed, [illegible] hrs.
Polyurethane, liquid, [illegible] component	Mosites 1504 (V)	[illegible]	[illegible]	4130M	Grit Blast, [illegible] Mils Flame Sprayed [illegible] Aluminum	Same as above	1-No failure, [illegible] hrs.
Polyurethane, liquid, 3 component	Mosites 1504 (V)	[illegible]	[illegible]A	4130M	Grit Blasted	Same as above	1-Failed, [illegible] hrs.
Polyurethane, liquid, [illegible] component	Mosites 1505 (V)	[illegible]	[illegible]	4130M	Grit Blast, [illegible] Mils Flame Sprayed [illegible] Aluminum	Same as above	1-Failed, [illegible] hrs.
Polyurethane, liquid, [illegible] component	Mosites 1505 (V)	15	[illegible]	4130M	Grit Blast	Same as above	1-Failed, [illegible] hrs.
Polyurethane, liquid, 2 component	Acushnet E-[illegible] (V)	[illegible]	[illegible]D	4130M	Grit Blast	Brush, room temperature cure. (Primer and adhesive used not known)	2-Failed, [illegible] hrs.
Polyurethane, liquid, 3 component	Acushnet E-[illegible] (V)	[illegible]	[illegible]A	4130M	Grit Blast	Same as above	2-Failed, [illegible] hrs.
Polyurethane, liquid, ceramic frit filled, 2 component	Magna Coatings & Chem. Corp. Laminar X-500, GAEC #1012 Epoxy Primer (5)(6)	15	Unknown	4130M	Grit Blast	Spray, room temperature cure	2-Failed, [illegible] hrs; 1-No failure, 639 hrs.

(1) L - Applied by LTV, V - Applied by vendor.
(2) Furnished by vendor.
(3) Material applied and cured during laminate cure by Hudson Engineering Co., Houston, Texas.
(4) Number of specimens tested as indicated.
(5) Grumman Aircraft Engineering Corp. #1012 Epoxy Primer.
(6) Applied by Grumman Aircraft Engineering Corp. Coating used on HS Denison foils.

2.10.3 CAVITATION-EROSION

NASL rotating disc cavitation tests were run on two Phase II coating systems. Details of the coating systems, test procedure and results are shown in Table 2-40.

Rotating disc cavitation-erosion results for Phase III coatings are presented in Section 4.7 of the basic report.

TABLE 2-40

Naval Applied Science Laboratory Rotating Disc Cavitation - Erosion Results For 20 and 60 Mil Mosites 60125 Neoprene and Mosites 1500 Polyurethane Colandered Sheet Applied on SAE 1020 Steel. (1)

COATING SYSTEM AND APPLICATION PROCEDURE	20 Mil Thickness Velocity (FPS)			60 Mil Thickness Velocity (FPS)		
	100	125	150	100	125	150
(1) Alkaline clean surfaces. (2) Prime with Coast Pro-Seal 777P and dry 30 minutes at room temperature. (3) Apply 20 and 60 mil Mosites 60125 colandered neoprene sheet. (4) Vacuum bag and cure 1 hour in autoclave at 325°F. and 50 psig.	Adhesive Separation Coating Lost in Test	Partial Adhesive Separation	Adhesive Separation Coating Lost in Test	No Damage	No Damage	No Damage
(1) Alkaline clean surfaces. (2) Prime with Mosites 1500 primer and air dry 15 minutes at room temperature plus 15 minutes at 160°F. (3) Apply Mosites 1500 adhesive and dry 15 minutes at room temperature plus 15 minutes at 160° F. (4) Apply 20 and 60 mil Mosites 1500 colandered polyurethane sheet. (5) Vacuum bag and cure 1 hour in autoclave at 325°F. and 50 psig.	No Damage	No Damage	Erosion Damage	No Damage	No Damage	Erosion Damage

(1) Test Liquid - Fresh Water. Water Pressure - 15 Psig. Shaft Speed - 3200 RPM. Flow Rate - 9.5 Gpm. Inlet Temperature - 5°F. Outlet Temperature - 72°F.

2.10.4 COATING APPLICATION PROCEDURES

2.10.4.1 The coated static immersion specimens indicated in Table 2-35 were prepared as follows.

A. AISI 4330M

1. Application of Mosites 1500

a. Grit blast all surfaces.
b. Vapor degrease
c. Brush on thin coat of Mosites 1500 primer, air dry 15 minutes at room temperature and 15 minutes at 160°F, cool.
d. Brush on thin coat of Mosites 1500 adhesive, air dry 15 minutes at room temperature and 15 minutes at 160°F, cool.
e. Roll 20 mil, Mosites 1500 calendered polyurethane sheet on one (1) flat surface and all edges.
f. Vacuum bag and cure 1 hour in autoclave at 310°F and 50 psig.

2. Application of Coast Pro-Seal 777P and 793

a. Grit blast uncoated surface.
b. Solvent wipe.
c. Spray on thin coat of 777P primer, air dry 30 minutes.
d. Wipe edges of Mosites 1500 with toluene, air dry 15 minutes.
e. Apply five (5), 4 mil coats of 793 on uncoated surface and edges. Air dry 4 to 16 hours between coats. Cure 7 days at room temperature.

B. HY 100

1. Mosites 60125

a. Grit blast all surfaces.
b. Vapor degrease.
c. Brush apply a thin coat of Mosites 60125 primer, air dry 15 minutes at room temperature and 15 minutes at 160°F.
d. Brush apply a thin coat of Mosites 60125 adhesive, air dry 15 minutes at room temperature and 15 minutes at 160°F.
e. Roll 20 mils Mosites 60125 calendered neoprene sheet on all surfaces, overlapping on one surface and sealing along ends.
f. Vacuum bag and cure 1 hour in autoclave at 310°F and 50 psig.

2.10.4.2 The coated static immersion specimens indicated in Tables 2-36 and 2-37 were prepared as follows.

A. 100%, 95% and 90% neoprene coated, welded 17-4PH (H 1025)

1. Grit blast all surfaces.
2. Vapor degrease.
3. Mask 0.4 inch x 12 inch area along edge for two 95%

coated specimens. Mask [illegible] area [illegible]
coated specimens.

4. Brush apply a thin coat of Coast Pro-Seal [illegible] primer on all surfaces to be coated, air dry [illegible] minutes.

5. Roll 60 mils Mosites [illegible] calendered neoprene sheet on all surfaces to be coated. Overlap neoprene on one surface of the two 100% coated specimens and seal ends of all specimens.

6. Vacuum bag and cure 1 hour in autoclave at 310°F and 50 psig.

7. Remove masking from 95% and 90% coated specimens and solvent wipe uncoated areas.

B. The welded 17-4PH (H 1025) without coating were vapor honed prior to exposure.

2.10.4.3 The coating application procedure for the GAEC#1012/Laminar X-500 coated specimens indicated in Table 2-38 was not furnished with the specimens.